



Filamentous Trichomic Prokaryotes in Carbonaceous Meteorites : Indigenous Microfossils, Minerals, or Modern Bio-Contaminants?

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Filamentous Trichomic Prokaryotes in Carbonaceous Meteorites



**Detection of Valid Microfossils in Meteorites is Directly
Relevant to Fundamental Question of Astrobiology:
*Is Life restricted to Earth or does Life exist elsewhere in the Cosmos?***

Validity Criteria:

Biogenicity: *Are the putative microfossils unambiguously Biological?*

**Must be large enough to be autonomous organisms with
sufficient chemical and morphological complexity and
differentiation to distinguish them from abiotic mineral crystals
and coating artifacts**

Indigeneity: *Are the putative microfossils undeniably Indigenous?*

**Must be established that the possible microfossils are Indigenous
and not Mineral Artifacts or Modern Bio-Contaminants**



Instrumentation for Meteorite Study at NASA/MSFC - 1996-2011

ElectroScan Environmental Scanning Electron Microscope (ESEM)

Water vapor (10 Torr vacuum) 90-100,000X; SED; Noran EDS (Z> Boron)

Hitachi S-4100 Field Emission SEM (FESEM)

Cold cathode field emission electron gun; 20 - 300,000X;

**Secondary Electron (SED) & Backscattered Electron Detector (BSED); KEVEX
EDS - Lithium Drifted Silicon detector (Z>Boron)**

Hitachi S-3700N Variable Pressure Scanning Electron Microscope

Tungsten emitter electron gun; 5 - 300,000X; SED & BSED;

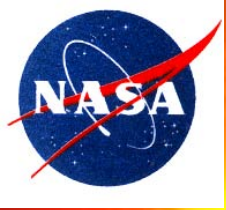
4 Pi EDS - Silicon Drifted Silicon Detector (Z>Boron)

FEI Quanta 600 (FESEM and ESEM)

Simultaneous SED and BSED images;

4 Pi EDS - Lithium Drifted Silicon detector (Z>Boron)

Olympus, Zeiss & Leitz Optical and Epifluorescence Microscopes



Flammonious Trichonine

Prokaryotes in Carbonaceous Meteorites

CONTAMINATION CONTROL

Study Confined to Freshly Fractured Interior Surfaces

Optical Microscopy to Observe Surface Cracks

Meteorite Fusion Crust and Old Cracks Avoided

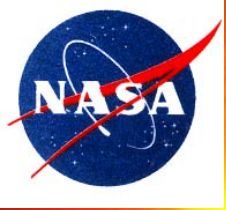
New Mount Stubs & Sterile Tools Used

Flame Sterilization of containers stubs & Tools

Long term storage in sealed vials @-80C or dessicator

Uncoated samples used - No contact with liquids

Sample into ESEM or FESEM chamber right after fracturing



Meteorites Investigated at NASA/MSFC



Carbonaceous Chondrites

CI1: **Alais, Ivuna & Orgueil**

C2 Ungrouped: **Tagish Lake**

CM2: **Murchison, Mighei, Murray & Nogoya**

CR: **Acfer 324;** CK4: *Karoonda;*

CO3: **Rainbow, Dar al Gani 749 & Kainsaz**

CV3: *Allende & Efremovka*

Stony Chondrites, Achondrites & Iron Meteorites

L4: *Nikolskoye & Barratta;* L/LL6: *Holbrook;*

Diogenite: *Tatahouhine;* Iron: *Henbury; 20 Thiel Mt.*

Italics: Remains of Microfossils Never Detected



Phenomenous Prokaryotic Prokaryotes in Carbonaceous Meteorites

Murchison CM2 Meteorite



**Fall: 10:59 A.M.
9/18/1969 - Murchison,
Australia**

**>100 kg. recovered –
Chondrules Present**

Magnetites U/Pb Age ~ 4.56 Gya
Cosmic Ray Exposure ~ 800 Kya





Murchison CM2 Meteorite



- **CM2 Carbonaceous Chondrite with Chondrules**
- **Extensive Alteration by Water on Parent Body**
Hydrous Phyllosilicates – Clay Minerals - Serpentine
Chemically Primitive - Except for Volatiles the Elemental Abundances ~ Solar Photosphere
~2.5 wt. % Carbon; ~ 3-11% Extraterrestrial Water,
- **Insoluble Organic Matter~Lignite Coal-Kerogen**
- **74 Amino Acids - (α -Aib, Gly, β -Ala & IVal) - Abundant**
Missing Amino Acids
(Phe, Tyr, Lys, His, Arg & Trp) -- Never Detected in Murchison or Orgueil
Inconsistent with Modern Bio-Contaminants



Murchison CM2 Meteorite



SAMPLES INVESTIGATED

**1 stone: (4.2 gm) E12391: *Sand Pits near Produce Stand*
*Tr. Univ. Melbourne 3564 - Nature Phys. Sci. 230, 18-20***

Courtesy: Dr. William Birch

**1 stone (3.5 gm) E4806: *Near Murchison East*
*Prof. J. Lovering 10-2-1971***

**1 stone (2.5 gm) E12314: *Near Abbington Farm, Murchison*
Courtesy: Dr. William Birch
Victoria Museum,
*Melbourne, Australia***

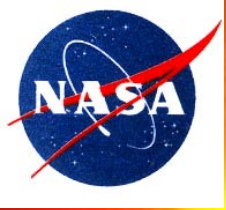


Orgueil CI1 Meteorite

Fall: May 14, 1864



**Over 20 black stones 18 km EW Scatter Ellipse ($43^{\circ} 54' \text{ N}$; $01^{\circ} 24' \text{ E}$)
Villages of Orgueil (Tarn-et-Garonne), Campsas & Nohic, France**



Orgueil CI1 Meteorite



- **CI1 Carbonaceous Chondrite - No Chondrules**
- **Micro-regolith Breccia (Particulates 1 nm–100 μ)**
- **Extensive Aqueous Alteration on Parent Body**
Silicate Minerals converted to Hydrous Phyllosilicates
Clay Minerals - Serpentines
- **Primitive Chemistry – *Except for Volatiles the Elemental Abundances of Orgueil ~ Solar Photosphere***
• ~3.5 wt% C; ~ 17-22% Extraterrestrial Water,
62.5% Chlorite - $(\text{Fe,Mg,Al})_6(\text{Si,Al})_4\text{O}_{10}(\text{OH})_8$
6.7% Epsomite $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$ & Ammonium Salts
- **Insoluble Organic Matter ~ Bitumen or Kerogen**



Orgueil CI1 Meteorite

SAMPLES INVESTIGATED

Musée Nationale d'Histoire Naturelle, Paris

- 1 stone: MNHP #S219: (0.5 gm). *Courtesy: Dr. Claude Perron*
- 2 stones: (0.6 gm & 0.3 gm). *Courtesy: Dr. Martine Rossignol-Strick*
- 1 stone: Monbequi MNHP#225: (0.305 gm). *Dr. Brigitte Zanda*
- 1 stone - Campsas MNHP#246 (0.03 gm). *Dr. Brigitte Zanda*

DuPont Meteorite Collection
Planetary Studies Foundation, Chicago

- 2 stones: (0.4 gm & 0.1 gm). *Courtesy: Dr. Paul Sipiera*



filamentous Trichomic Prokaryotes in Carbonaceous Meteorites

TRICHOMIC CYANOBACTERIA

Oxygenic Photosynthetic Prokaryotes

**Photoautotrophs-Use H_2O as Photoreductant &
 CO_2 as Source of C for Energy & release Oxygen**
Some are Facultative Chemoheterotrophs and use

PSII for *Anoxygenic Photosynthesis of H_2S*

**Reproduce by Fragmentation & Hormogonia;
Binary Fission, Multiple Fission, Spores/Akinetes**

**Precise Size & Characteristics of Cells, Sheath,
Trichome & Filament Taxonomic Diagnostic**



Phanerozoic Prokaryotes in Carbonaceous Meteorites

MODERN CYANOBACTERIA

Samples Investigated

Plectonema (Lyngbya) wollei–Lake Guntersville, Alabama
Hoover Collected, May, 2004 (Growing Environmental Sample)

Lyngbya (Leptolyngbya) subtilis – Lake Michigan, A. St. Amand,
Phycotech, Inc. (Fixed Environ. Sample)

Oscillatoria lud – UTex Coll. LB 1953 (Axenic Culture at NSSTC)

Arthrospira platensis– Carolina Biological Axenic Culture at NSSTC

Tolypothrix distort–Carolina Biological Axenic Culture at NSSTC

Calothrix membranaceae–Carolina Biological Axenic Culture NSSTC

Cylindrospermum sp. – Carolina Biological Axenic Culture NSSTC

Calothrix sp.–Little White River, Oregon, A. St. Amand, Phycotech.
(Fixed Environmental)

Microcoleus chthonoplastes–L. Gerassimenko, INMI Axenic Culture



Phosphorite- Lower Cambrian, Khesen fm., Tommotian Stage, Khubsugul, Mongolia **Prokaryotes in Carbonaceous Meteorites** **FOSSIL CYANOBACTERIA**

Samples Investigated

**Phosphorite- Lower Cambrian, Khesen fm.,
Tommotian Stage, Khubsugul, Mongolia**

Siphonophycus robustum (Schopf) Knoll et al. 1991

**Tufa-genic rocks - Upper Archaean (Lopian),
Northern Karelia (2.8 Ga)**

*Samples Courtesy: Dr. Alexei Yu. Rozanov,
Paleontological Institute, RAS, Moscow*



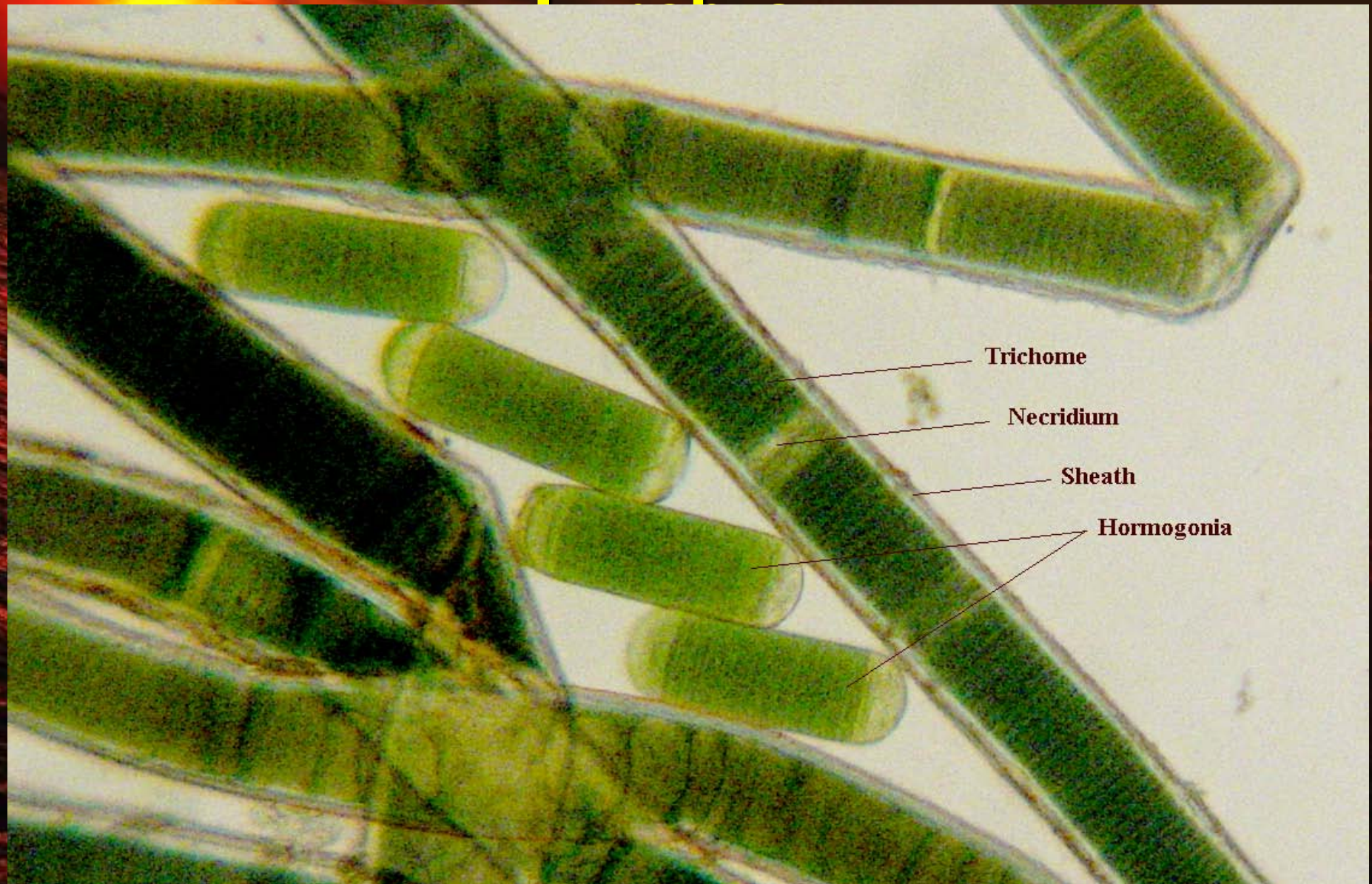
Cyanobacterial Morphology



- ***Trichome***: Linear Chain of Cells - Often in Sheath
- ***Sheath***: Slimy, mucilaginous, colloidal, non-cellular (fine, thick, or lamellated) envelope composed mainly of hydrated polysaccharides
- ***Filament***: Trichome with Polysaccharide Sheath
 - Filament can be Polarized, Uniseriate or Multiseriate, Unbranched; True or False Branching; Constricted; Isodiametric or Tapered*
- **Reproduction by Hormogonia or Akinetes**
- **Nitrogen Fixation by Heterocysts**
- **Gliding Motility Leaves Twisted Hollow Sheaths**



Trichomic Cyanobacteria: Filaments and Hormogonia of





Taxonomy of Cyanobacteria



NON-FILAMENTOUS

Order Chroococcales: - Unicellular rods and cocci

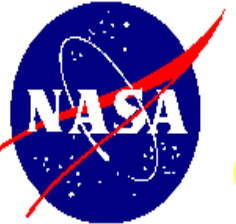
(e.g., *Synechococcus*, *Microcystis*, *Gloeotheca*, *Aphanothece*)

Inconclusive Morphology---Convergence with many other Bacteria,
Archaea, Algae, and Abiotic Forms

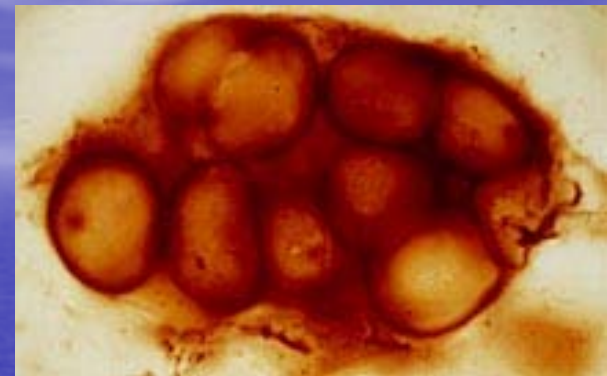
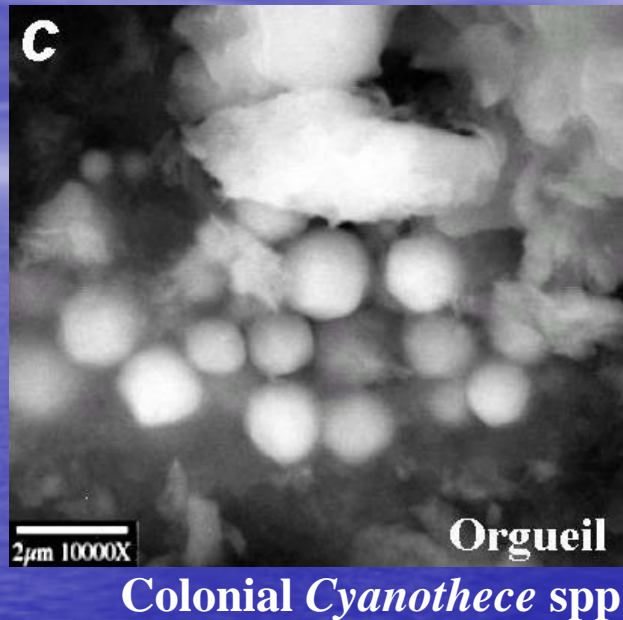
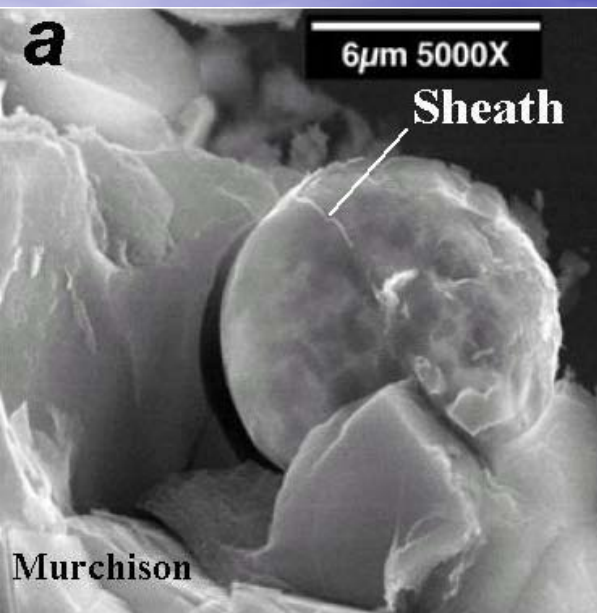
PSEUDO-FILAMENTOUS

Order Pleurocapsales - Unicellular cyanobacteria aggregated by shared outer wall layers:

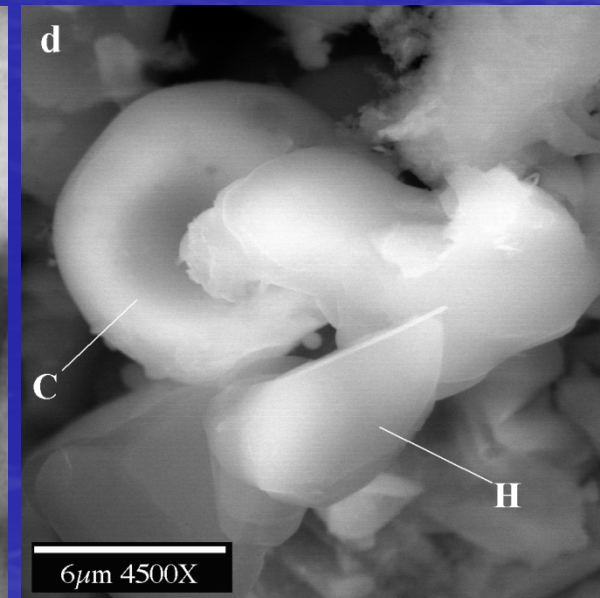
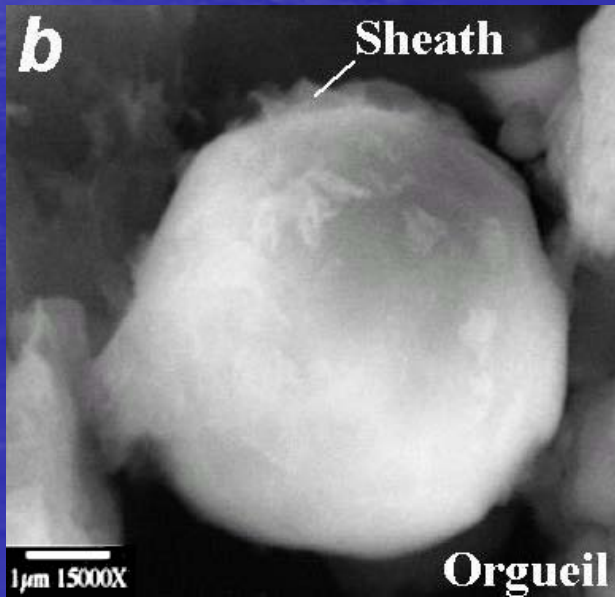
(e.g., *Dermocarpa*, *Chroococcidiopsis*, *Pleurocapsa*)



Morphotypes of Order *Chroococcales*: Cyanobacteria in Murchison & Orgueil



**Bitter Springs fm.
850 MA**
Myxococcoides minor



Embedded Coccoidal &
Hemispherical (1-8 µ)
forms in Carbon Envelopes ~
Gleoeocapsa spp.

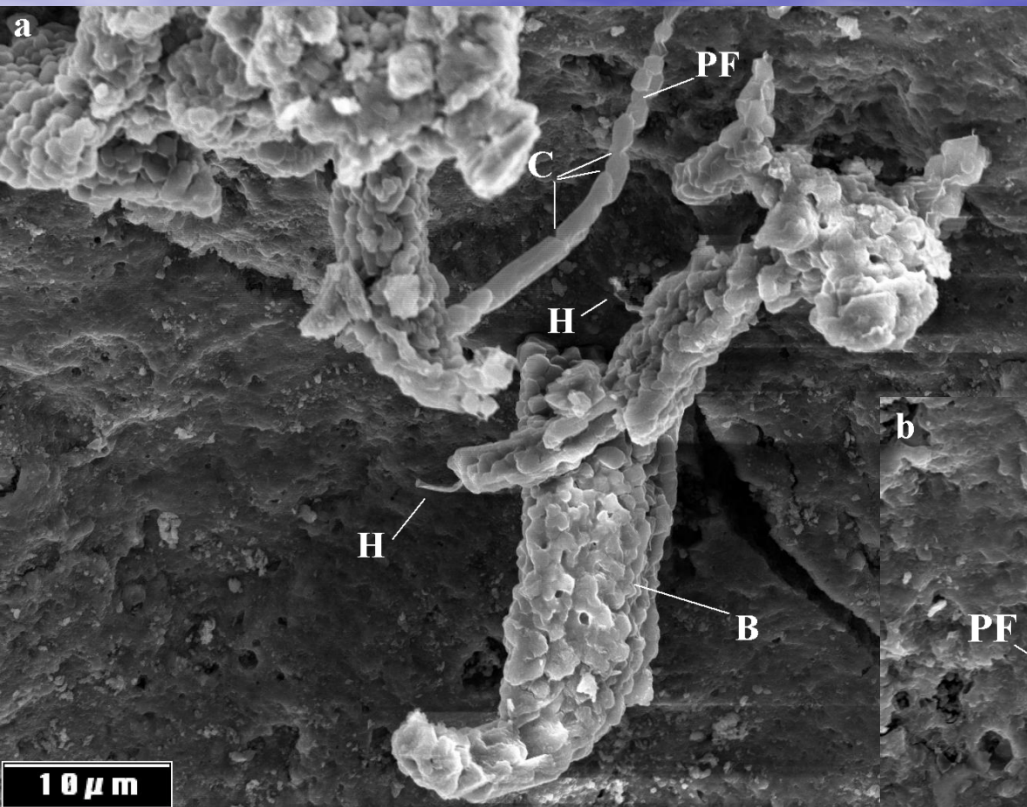
**Common but not Definitive –
Simple Morphologies are not
Unambiguously Biological in
Origin**



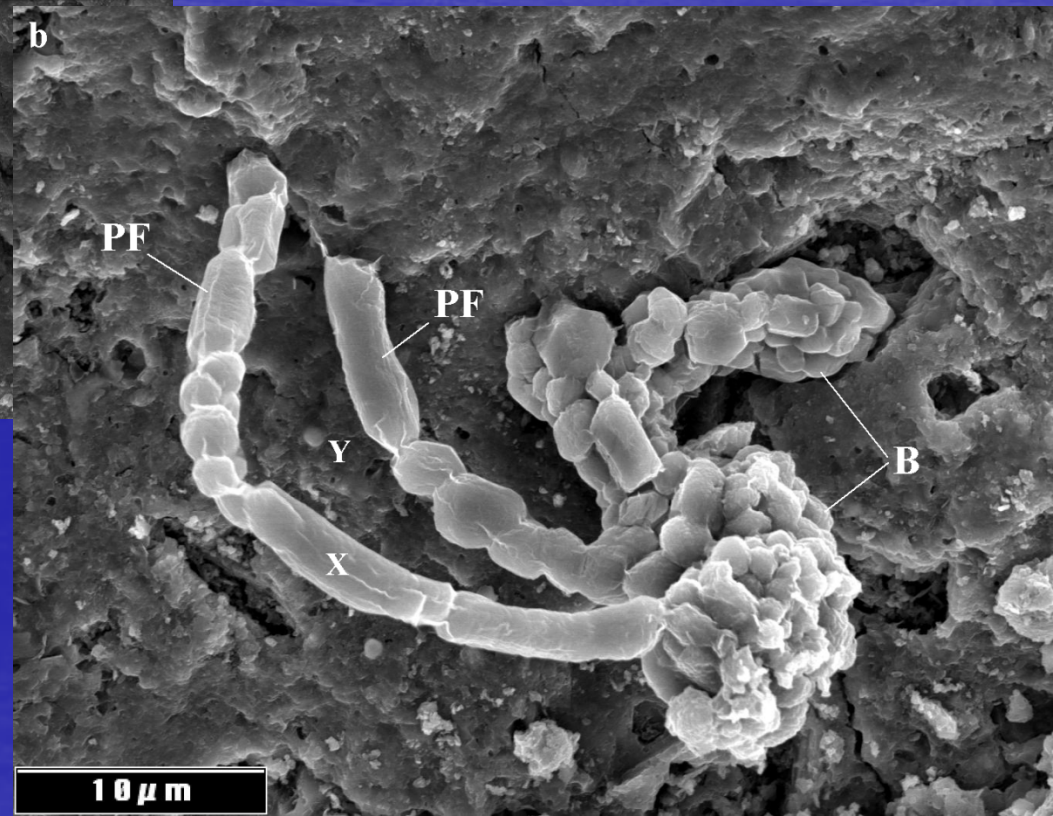
Morphotypes of Order: *Pleurocapsales* Cyanobacteria in Orgueil



**RARE-Found
only in one
Sample of Orgueil**



**Polygonal Coccoids in
Pseudo-filaments with
Terminal Hairs and
Carbonaceous Sheaths
~Baeocytes**





Taxonomy of Cyanobacteria

FILAMENTOUS ORDERS

Order Oscillatoriales: Trichomic Nonheterocystous Isodiametric Uniseriate or Multiseriate Filamentous Cyanobacteria

(e.g., *Oscillatoria*, *Spirulina*, *Lyngbya*, *Microcoleus*, *Phormidium*)

Morphological Convergence with Trichomic Sulfur Bacteria

Order Nostocales: Isodiametric Trichomes that form Heterocysts

(e.g., *Anabaenopsis*; *Anabaena*, *Nostoc*; *Cylindrospermum*)

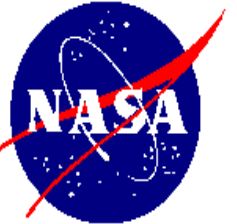
Tapered Trichomes that form Heterocysts at thick end of Trichome.

(e.g., *Calothrix*, *Rivularia*; *Tolypothrix*; *Gloeotrichia*)

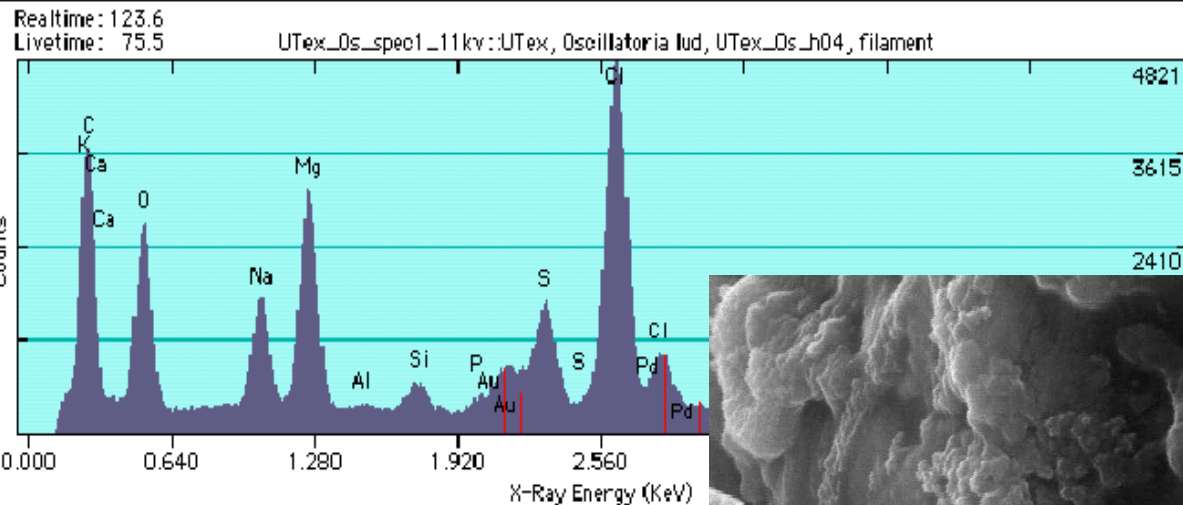
Order Stigonematales: Heterocystous with Branched Trichomes

(e.g., *Stigonema*; *Fischerella*, *Mastigocladopsis* or *Chlorogloeopsis*)

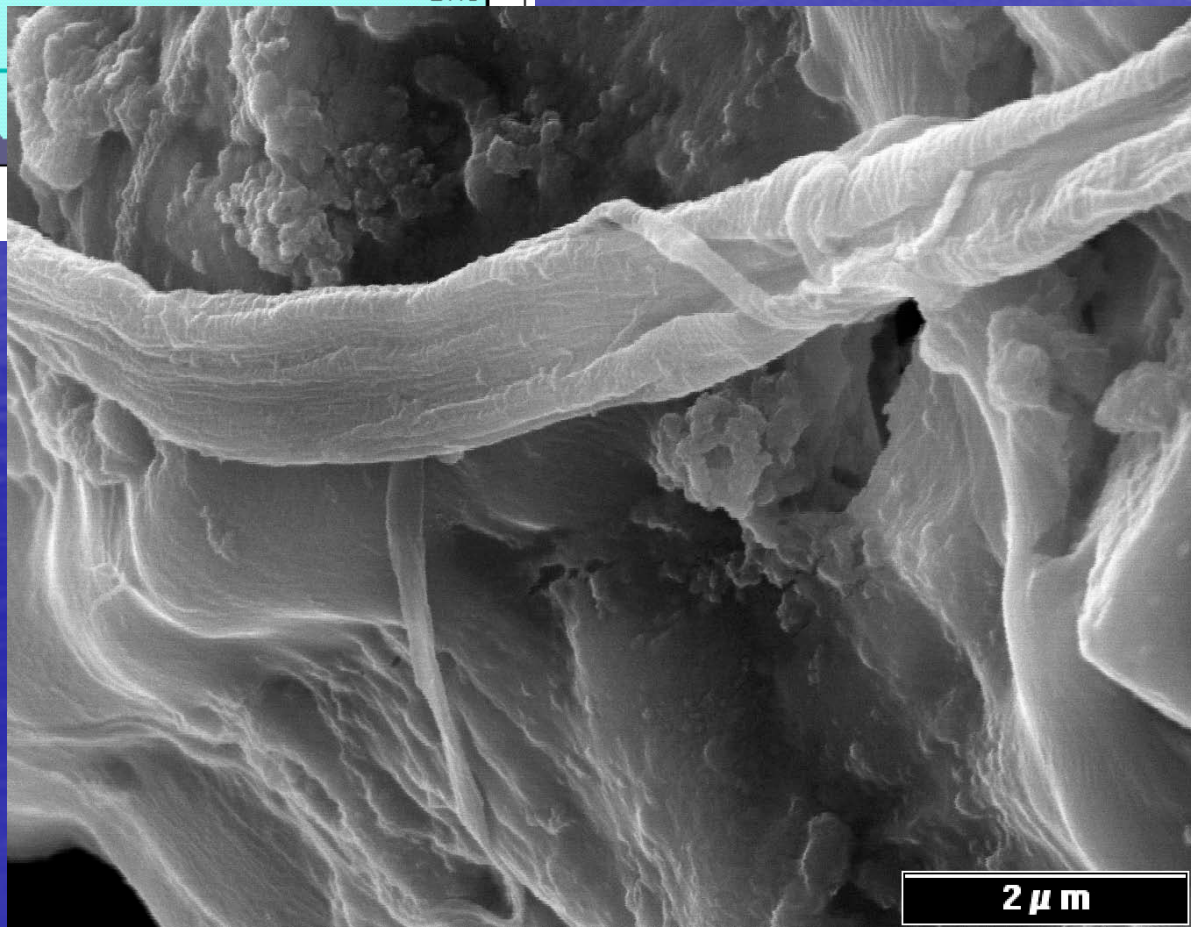
Well-Defined Sizes/Recognizable Morphologies of Polarized Filaments, Trichomes, Sheaths & Specialized Differentiated Cells (Heterocysts, Akinetes, Hormogonia & Branching)

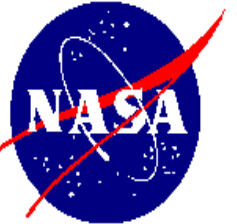


Morphotypes of *Oscillatoriales*: Living UTex *Oscillatoria lud*



C: 36%
O: 20%
N: 3.4%
S: 4.8%
Cl: 20%
Mg: 8%





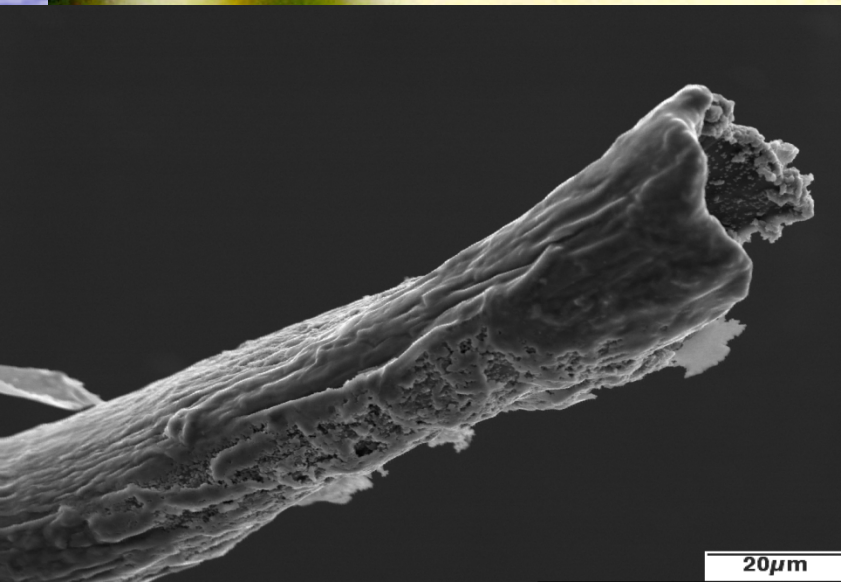
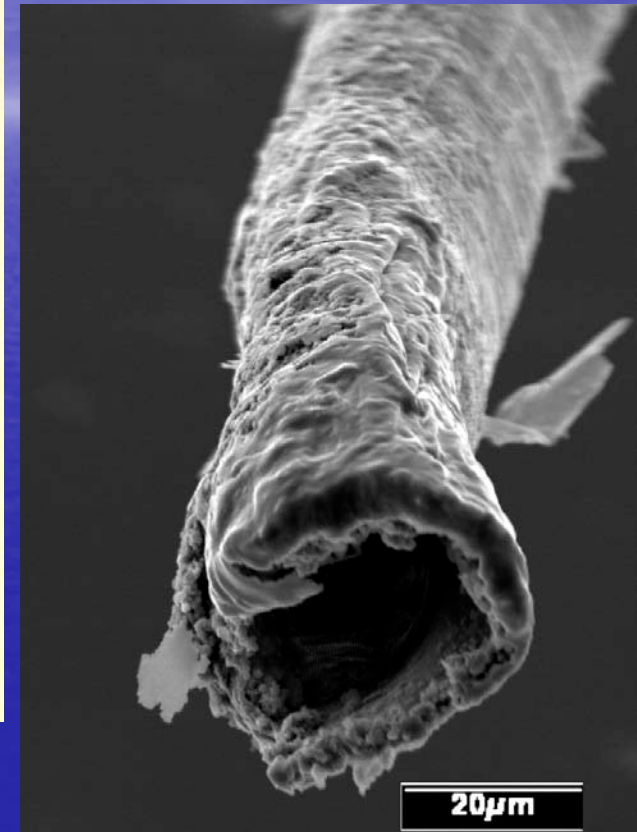
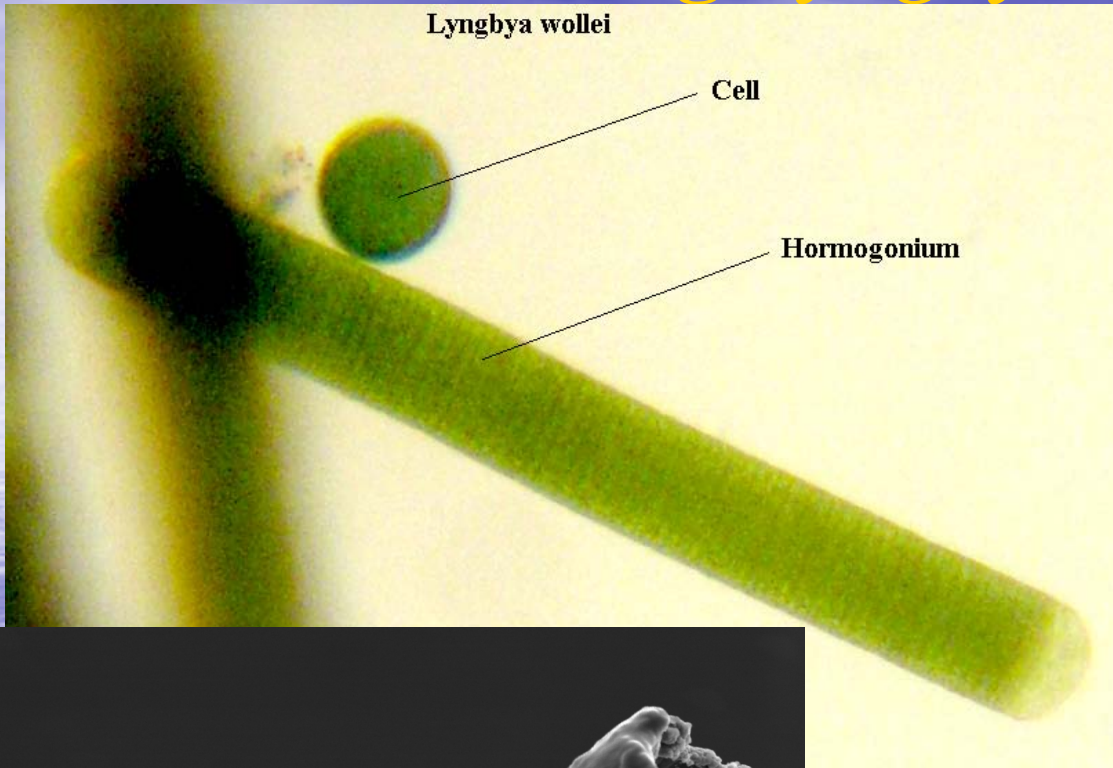
Morphotypes of *Oscillatoriales*: Living *Lyngbya wollei*



Lyngbya wollei

Cell

Hormogonium



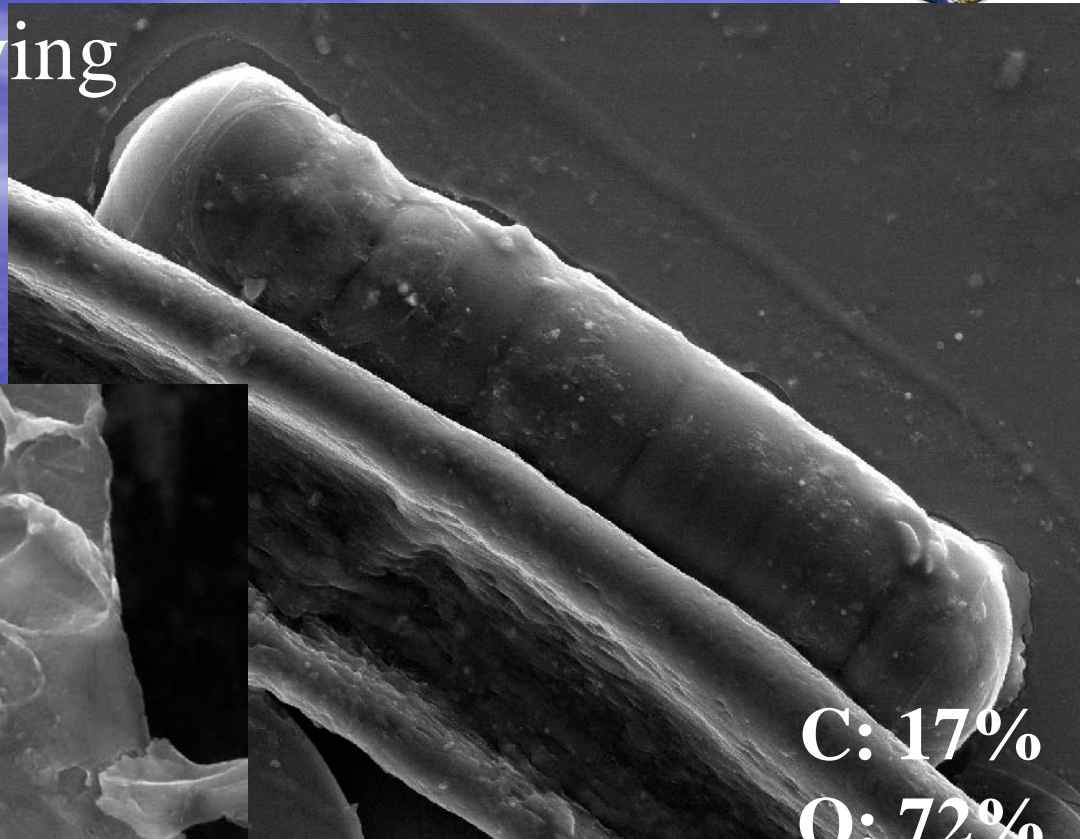
Disk-shaped cells 30μ dia.x4μ thick
O 58%; C 17%; Si 4%; N 3.2%;
S 2%; P .5%; **O/C=3.4**



O/C; C/N for Living *Lyngbya wollei*



Nitrogen Content of Living
Cyanobacteria
~2-18%



C: 17%

O: 72%

N: 8.2%

P: 0.6%

S: 0.3%

Si: 0.9%

O/C = 4.3

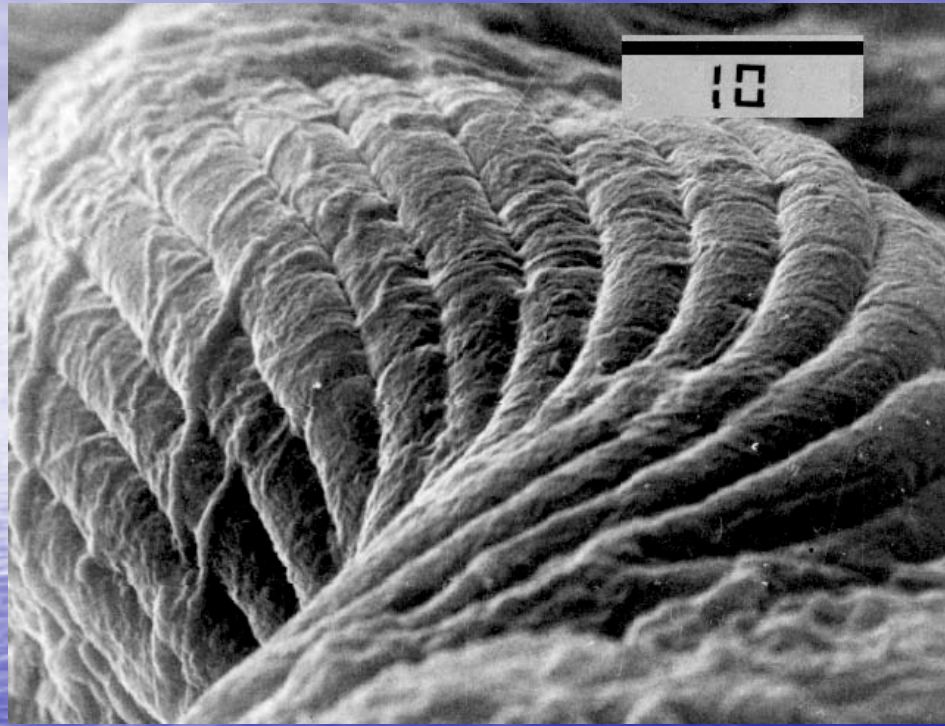
C/N = 2.1



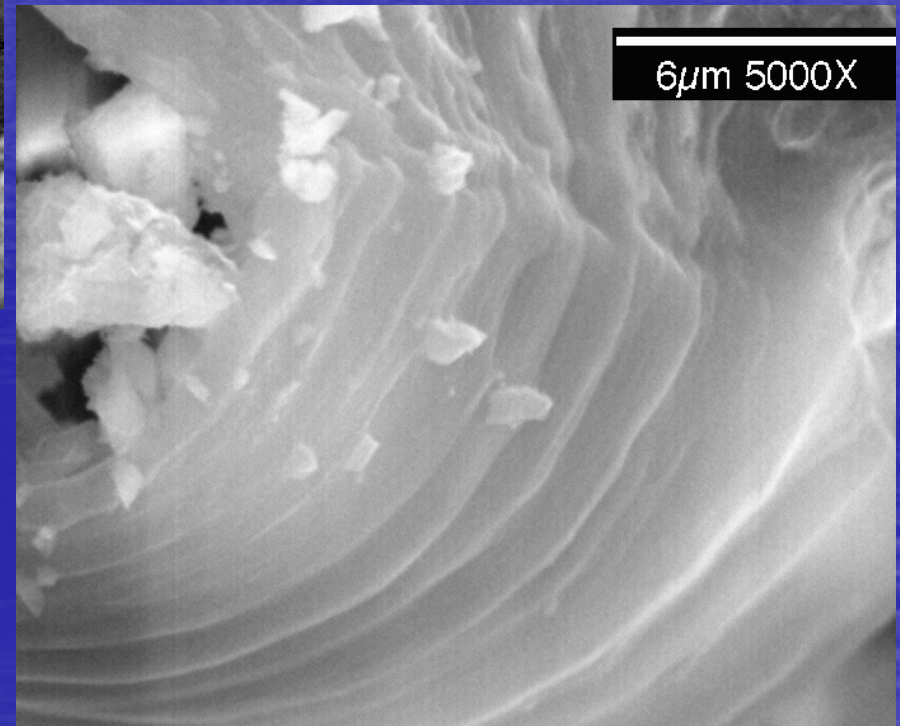
10 μ m



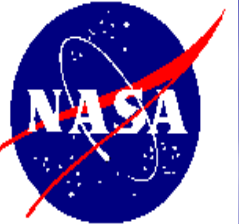
Morphotypes of Order *Oscillatoriales* in Murchison



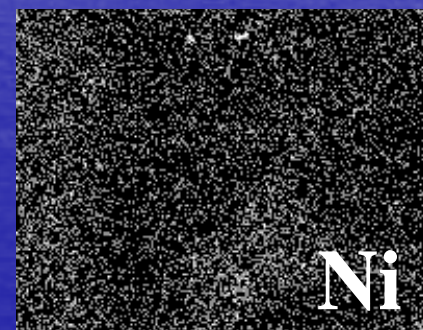
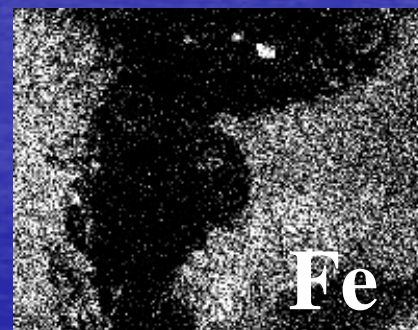
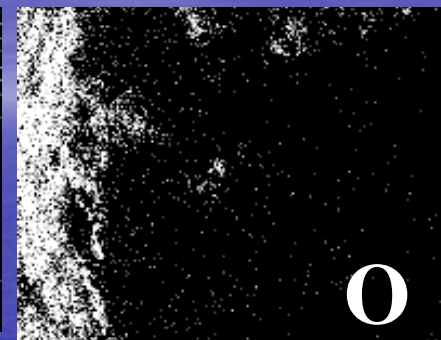
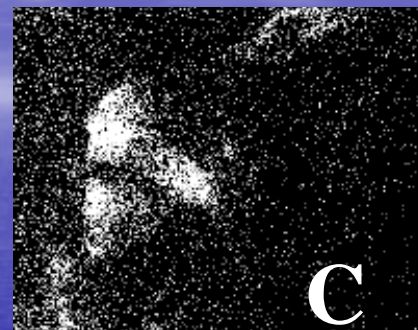
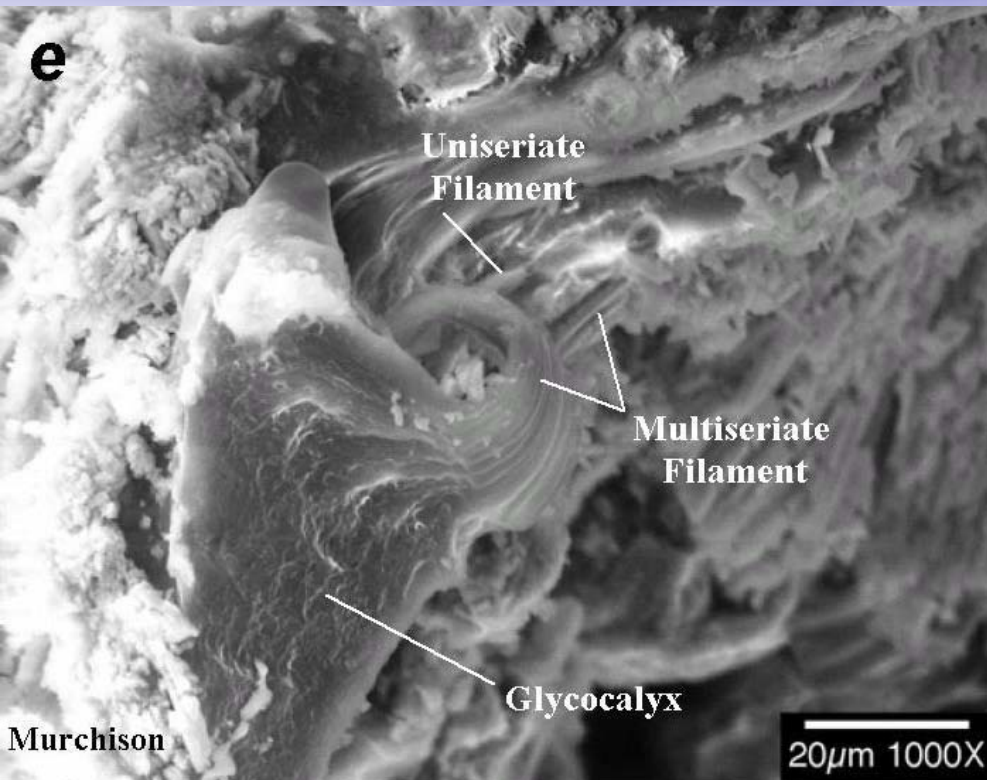
Murchison Multiseriate
Microfossil-Morphotype
of *Microcoleus* sp.



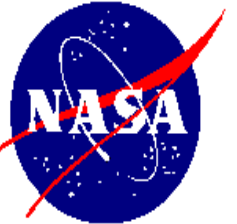
Living
Microcoleus chthonoplastes
in cyanobacterial mat
Photo : L. Gerasimenko
INMI-RAS



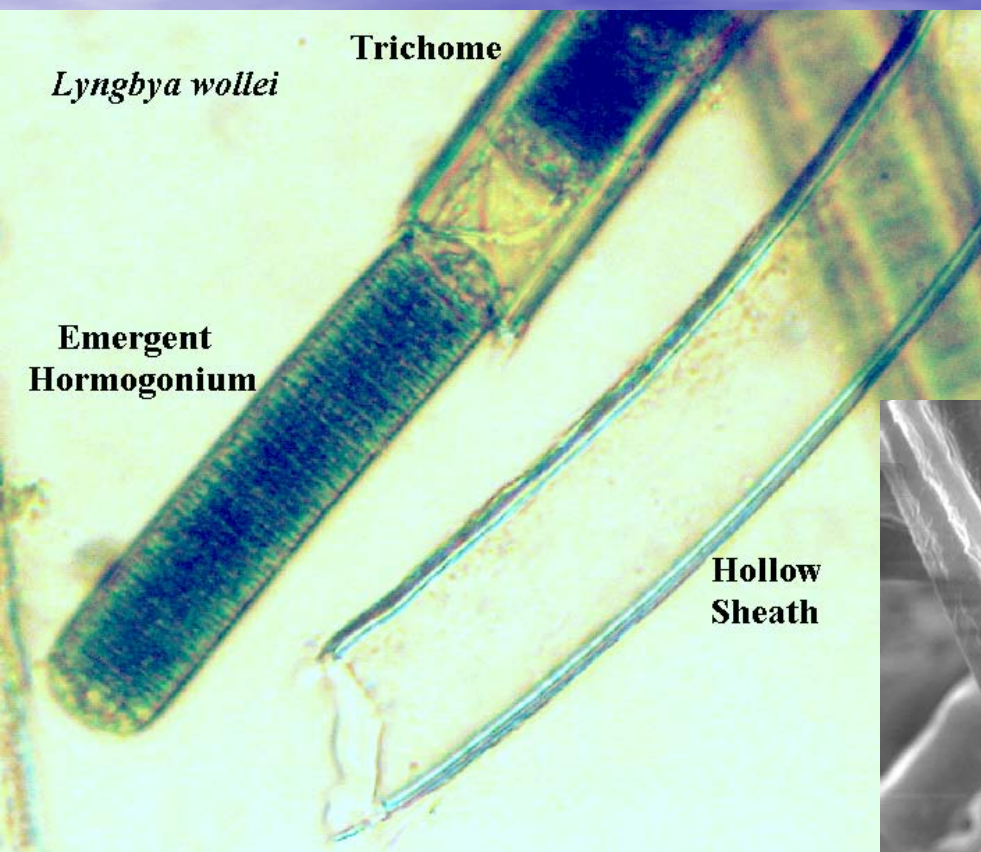
Morphotypes of Order *Oscillatoriales* in Murchison



2D EDS X-Ray Maps of Indigenous Microfossils in Murchison

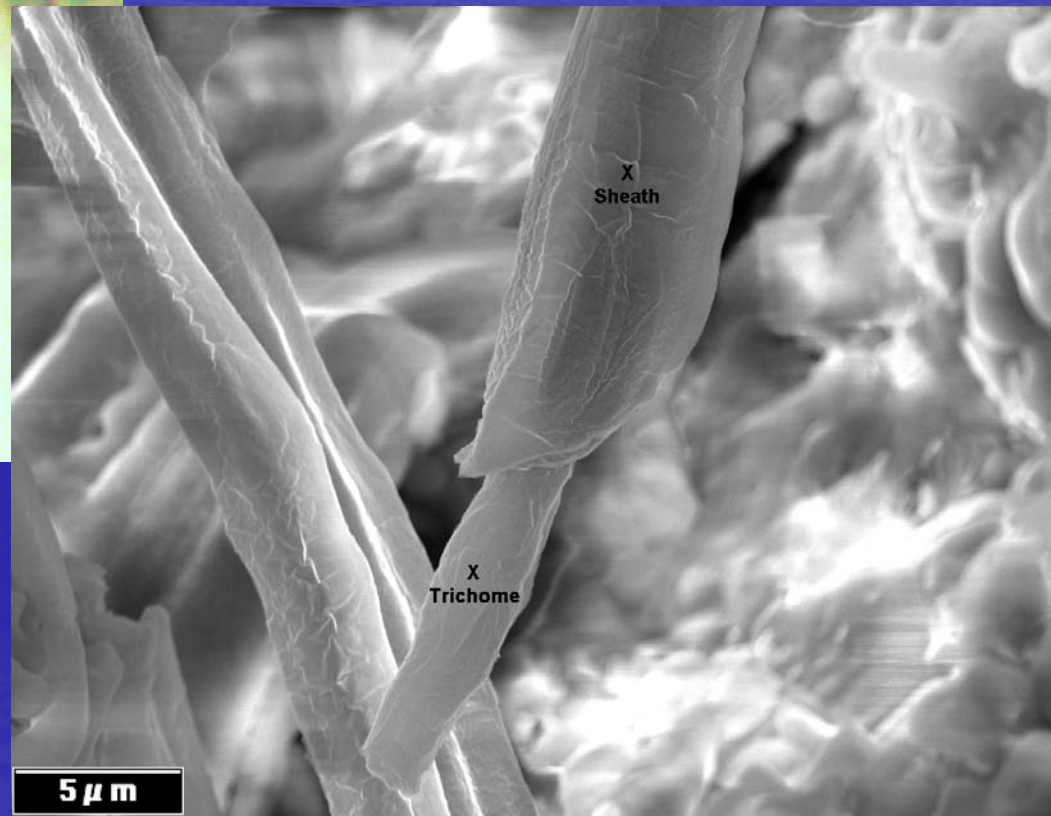


Morphotypes of Order *Oscillatoriales* in the Orgueil CI1 Meteorite



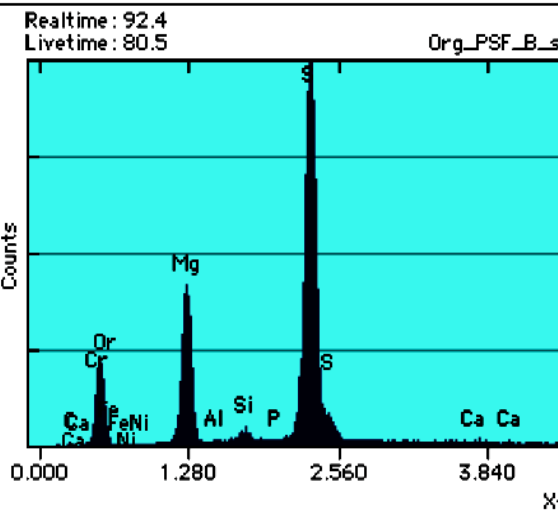
Orgueil Filament with
emergent hormogonium &
Hollow Flattened Sheath

Lyngbya wollei filament with
emergent hormogonium &
Hollow Sheath





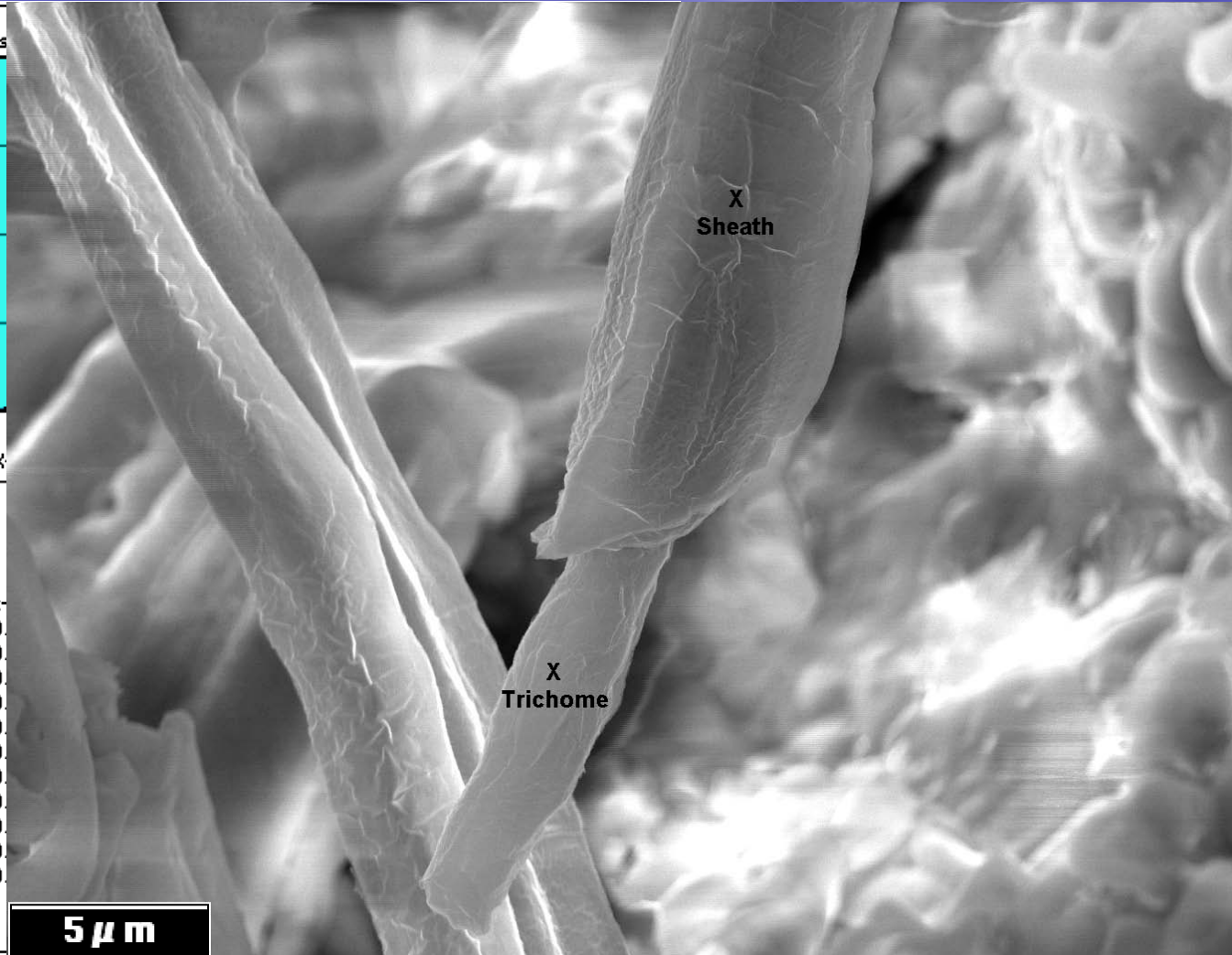
Morphotypes of Order *Oscillatoriales* in the Orgueil CI1 Meteorite



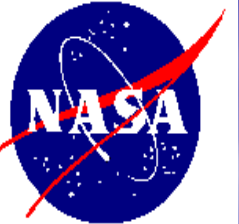
Quantitative Results for Org_B_h03b, sheath
Analysis: Bulk Method: Standardless
Acquired 14-Jul-2004, 15.0 KeV @10 eV/channel

Element	Weight %	Std. Dev.	MDL	Atomic %	k-
C ?	0.00	0.01	5.40	0.01	0
O	30.54	1.34	0.48	45.37	0
Mg	15.74	0.88	0.57	15.39	0
Al ?	0.00	0.00	1.92	0.00	0
Si ?	0.95	0.35	1.96	0.80	0
P ?	0.00	0.00	1.55	0.00	0
S	50.58	1.32	0.28	37.50	0
Ca ?	0.00	0.00	1.90	0.00	0
Cr ?	0.00	0.00	2.52	0.00	0
Fe ?	2.18	0.75	2.77	0.93	0
Ni ?	0.00	0.01	4.00	0.00	0
Total	100.00				

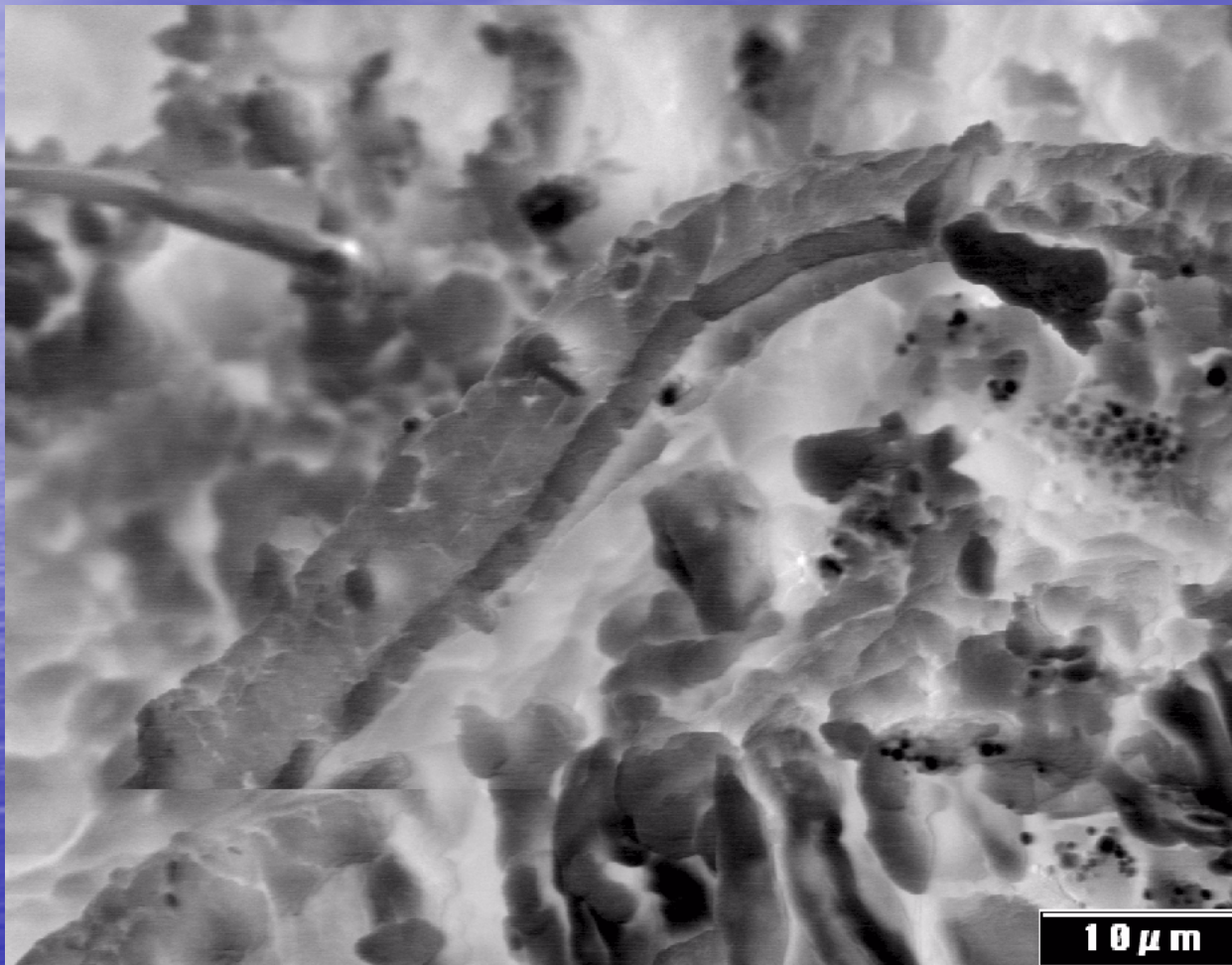
? These elements are statistically insignificant.



Sheath: Mg 15%; S 38%; O 45%; C < .1%; Fe 1%; O/C > 450



Cells in Thick Sheath of *Lyngbya sp.* Filament in Orgueil Meteorite



**Internal Structures – Trichome with Cylindrical
Cells ($2.5 \times 7.5 \mu$) in Thick Sheath (\sim *Lyngbya sp.*)**



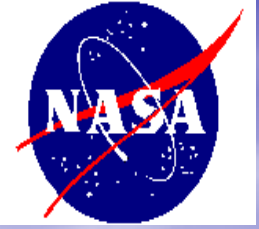
Morphotypes of Order *Oscillatoriales* in the Orgueil CI1 Meteorite



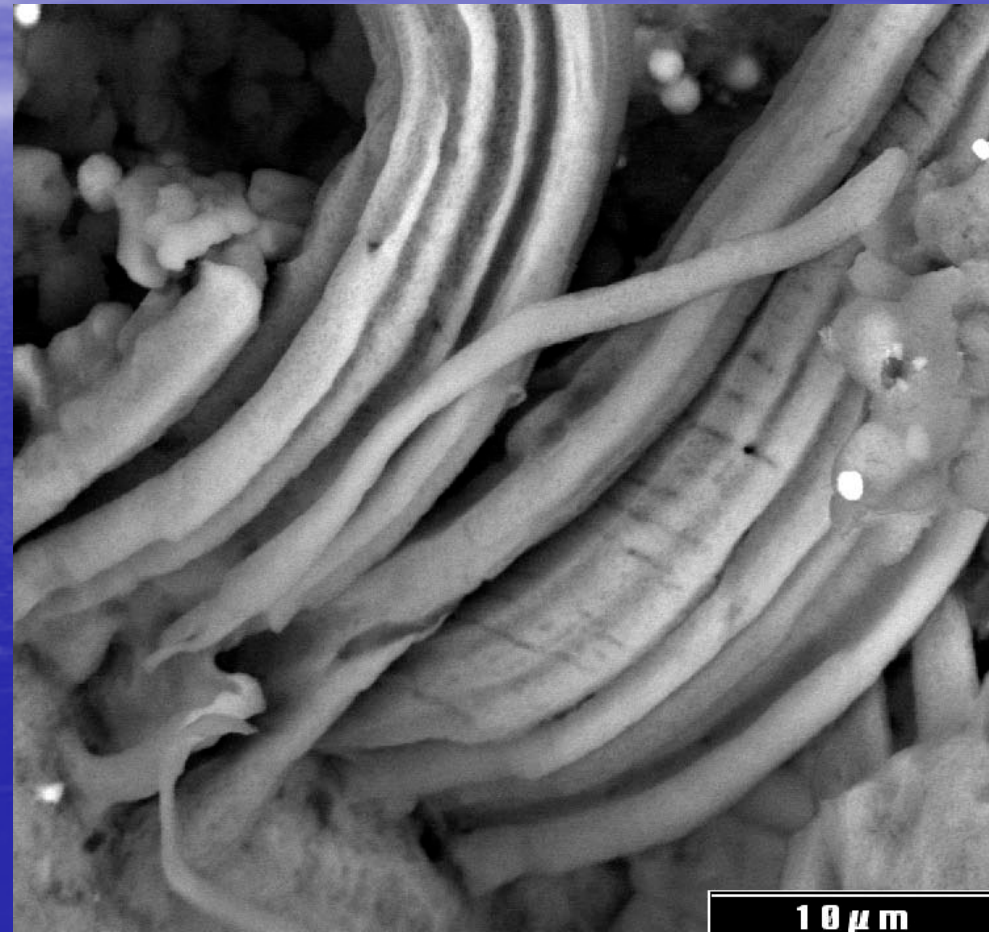
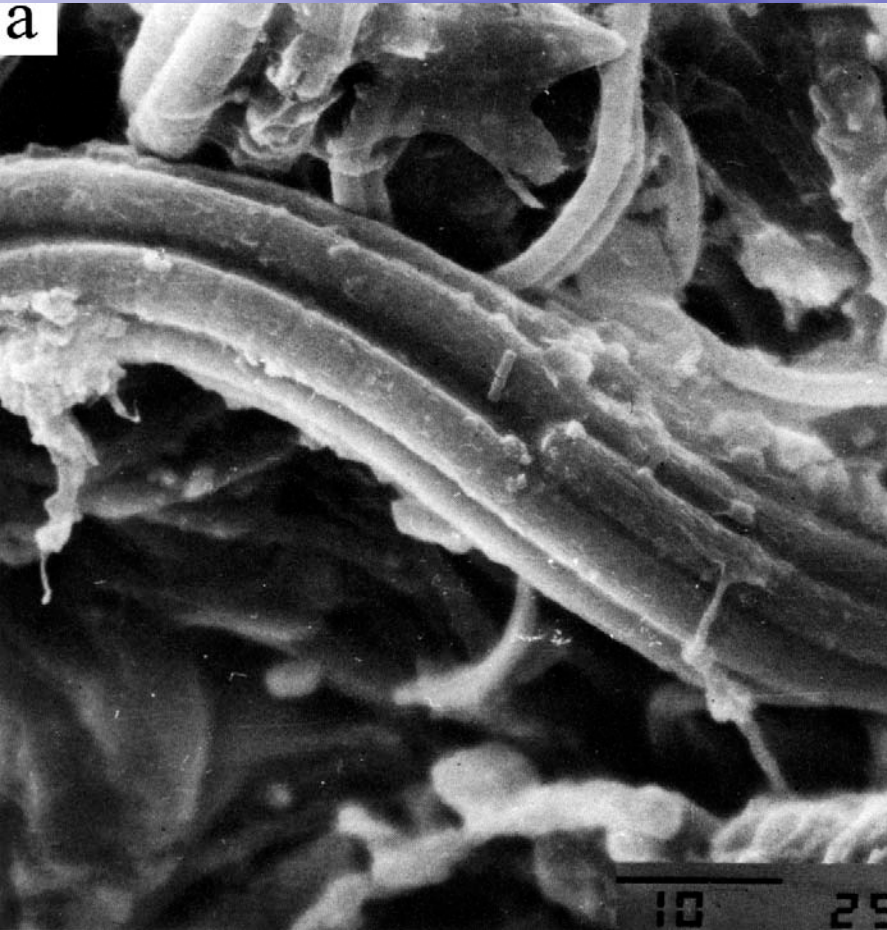
50 μ m



Spiral Filament (7 μ) of Uniseriate Trichomic (3 μ) Prokaryote
Morphotype of Cyanobacteria: *Lyngbya spiralis*



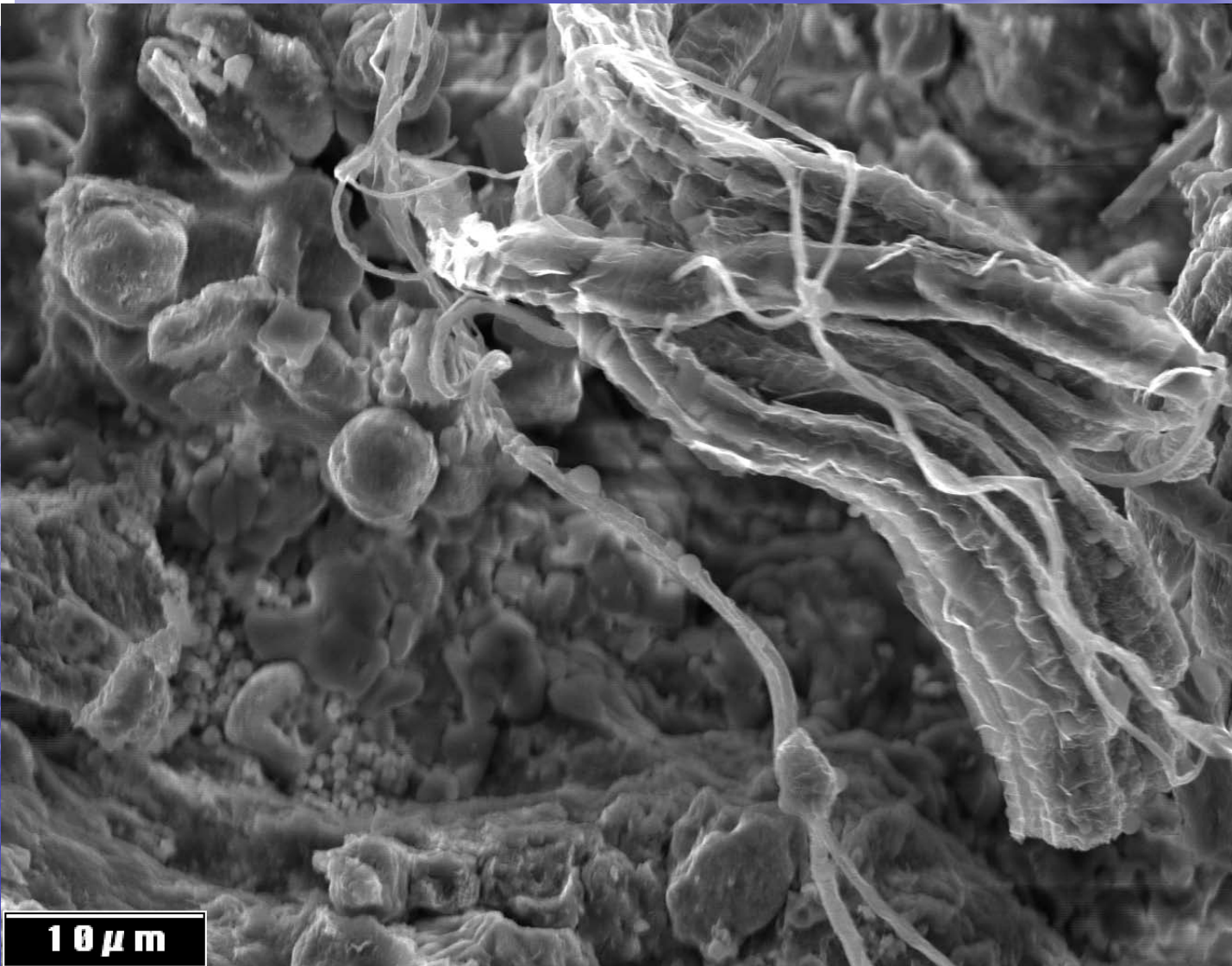
Morphotypes of *Oscillatoriales* in Orgueil & Living *Microcoleus*



Trichomes in common sheath of (a.) living *Microcoleus chthonoplastes* compared with (b.) Mineralized remains in Orgueil



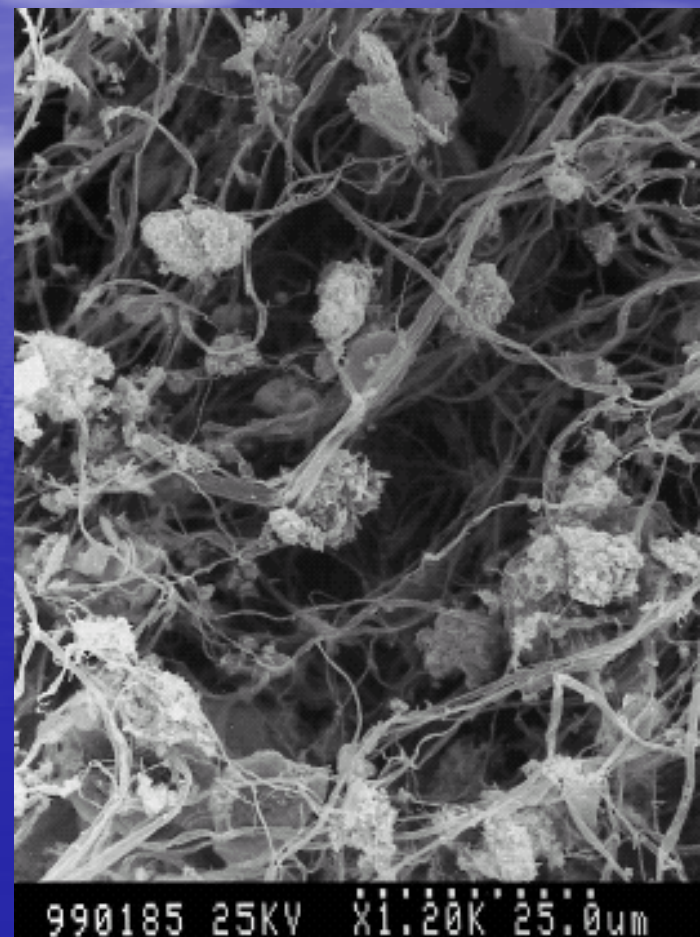
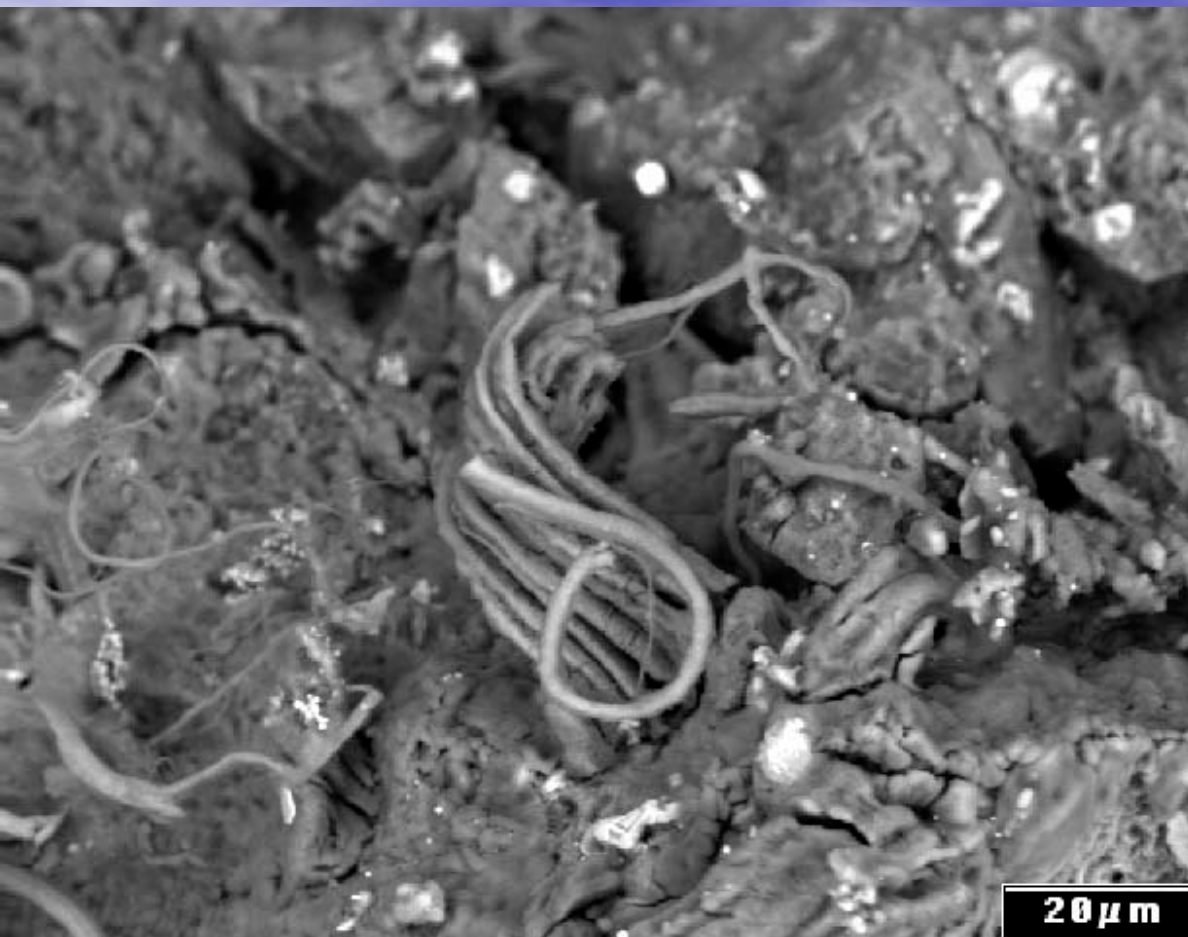
Morphotypes of *Oscillatoriales*: *Microcoleus* Mat in Orgueil



Trichomic Cyanobacterial Mat in Orgueil



Morphotypes of *Oscillatoriales*: *Microcoleus/Phormidium* Mat in Orgueil

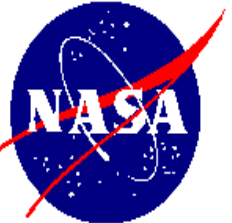


Mats of Oscillatoriales:
***Microcoleus/Phormidium* in**
Orgueil Meteorite and in
French Polynesia

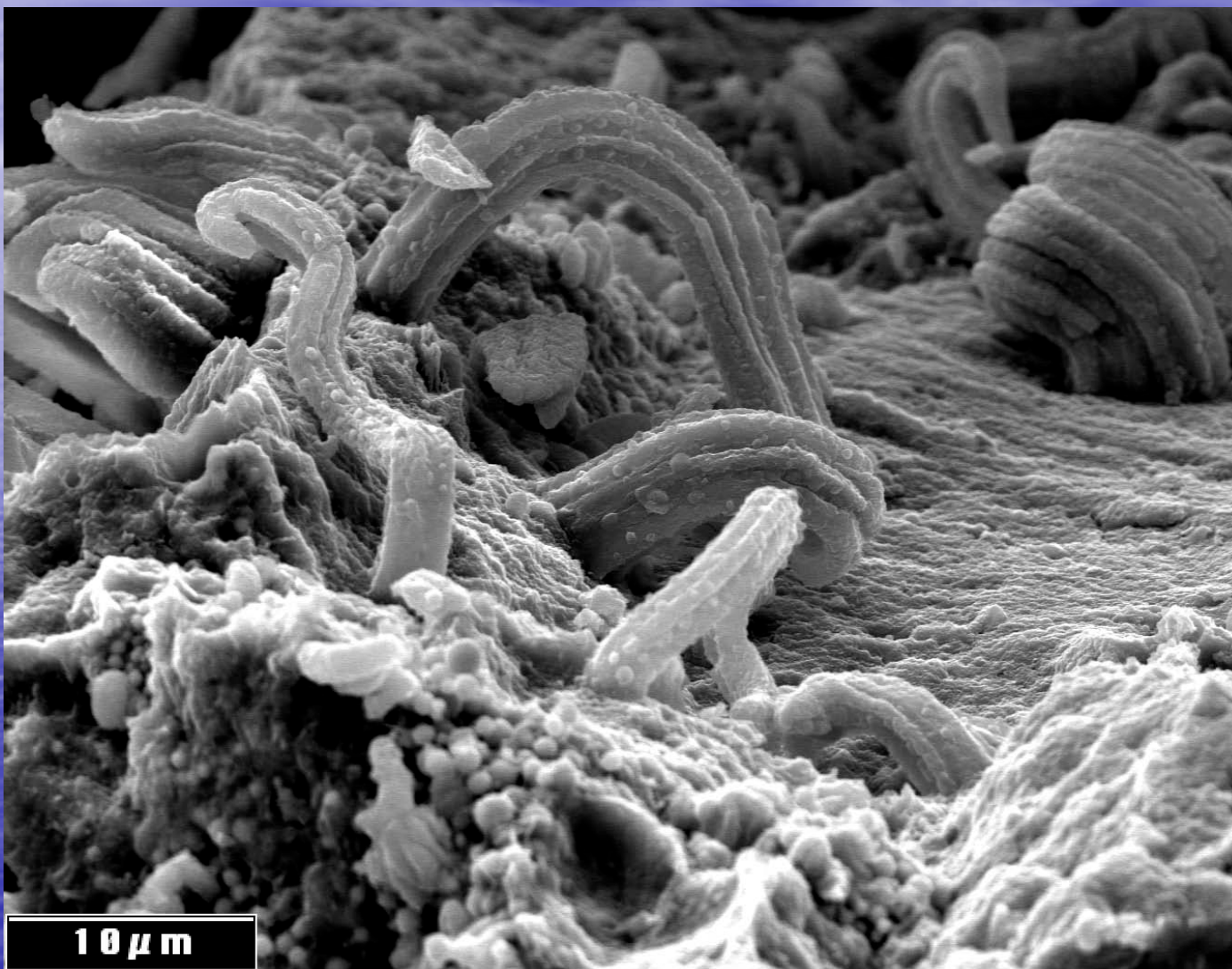
Microbialites in a modern lagoonal environment:
nature and distribution, Tikehau atoll (French Polynesia)

S. Sprachta^{a,*}, G. Camoin^{a,b}, S. Golubic^c, Th. Le Campion^d

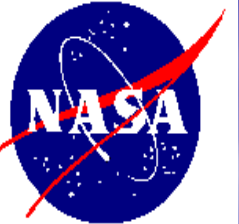
Palaeogeography, Palaeoclimatology, Palaeoecology 175 (2001) 103–124



Morphotypes of *Oscillatoriales*: Spirulina Mat in Orgueil



Morphotypes of Trichomic *Spirulina* spp.



Morphotypes of *Oscillatoriales*: *Oscillatoria* Mat in Orgueil



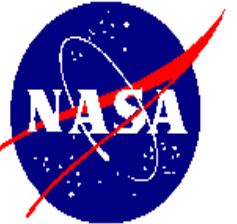
Morphotypes in Orgueil of Filaments ~ *Phormidium* sp.
(Trichomes uniseriate: Cells ~ 1 μ Wide X 1.5-2 μ long)



Morphotypes of *Oscillatoriales*: *Microcoleus* Filaments in Orgueil



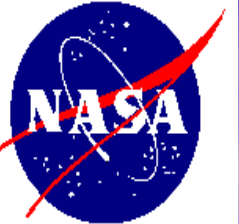
Embedded Filaments with Multiseriate Trichomes in Orgueil
Morphotypes of *Microcoleus chthonoplastes*



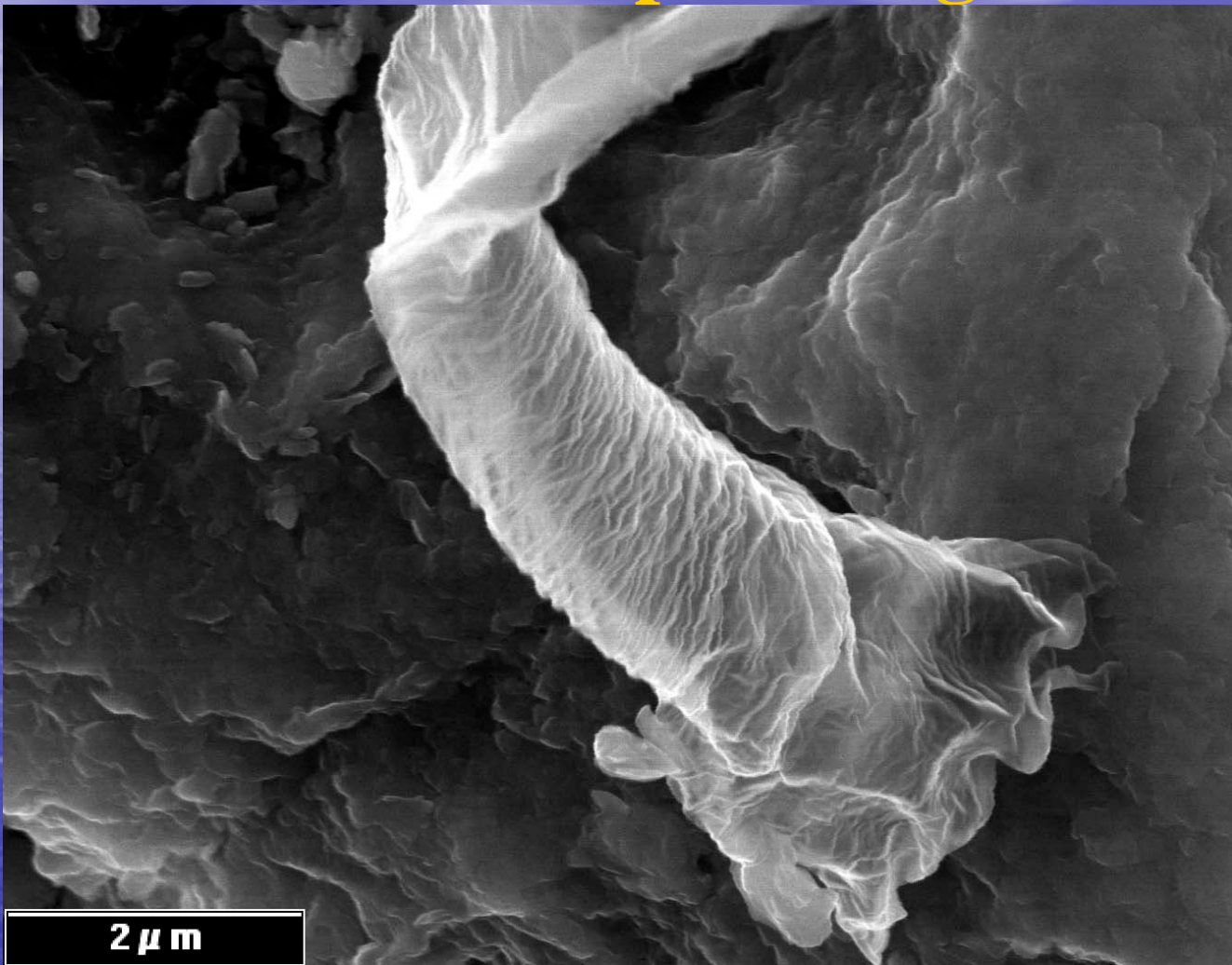
Morphotypes of *Oscillatoriales*: *Phormidium* Mat in Orgueil



Filaments with Emergent Hormogonia ~ *Phormidium* sp.;
O 42%; S 30%; Mg 14%; Fe 6%; C 5.4%



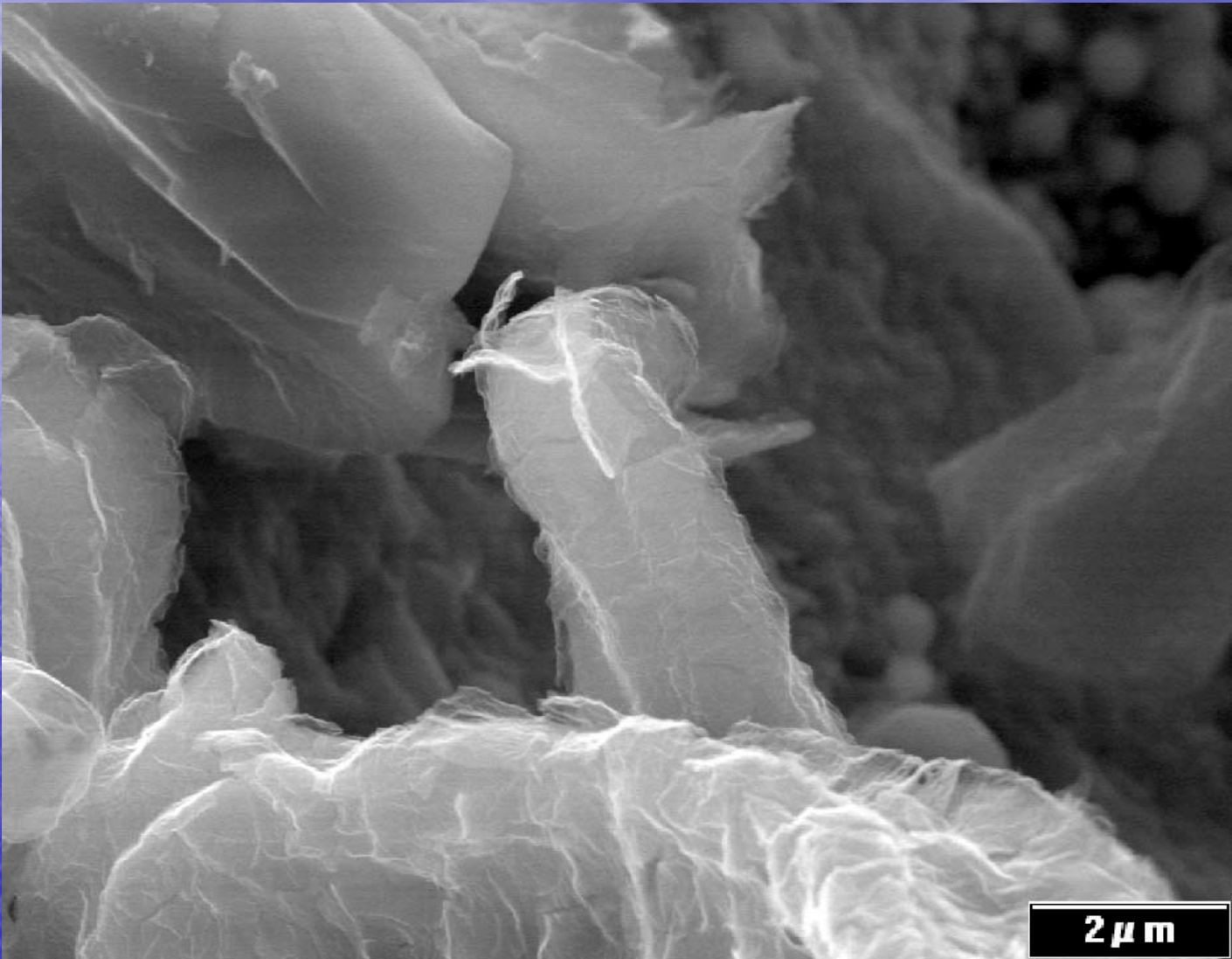
Morphotypes of *Oscillatoriales*: *Phormidium* sp. in Orgueil



**Attached Terminal End (Diameter 3 μ) of 1.8 μ Hollow & Flattened
Carbonized Sheath in Orgueil**



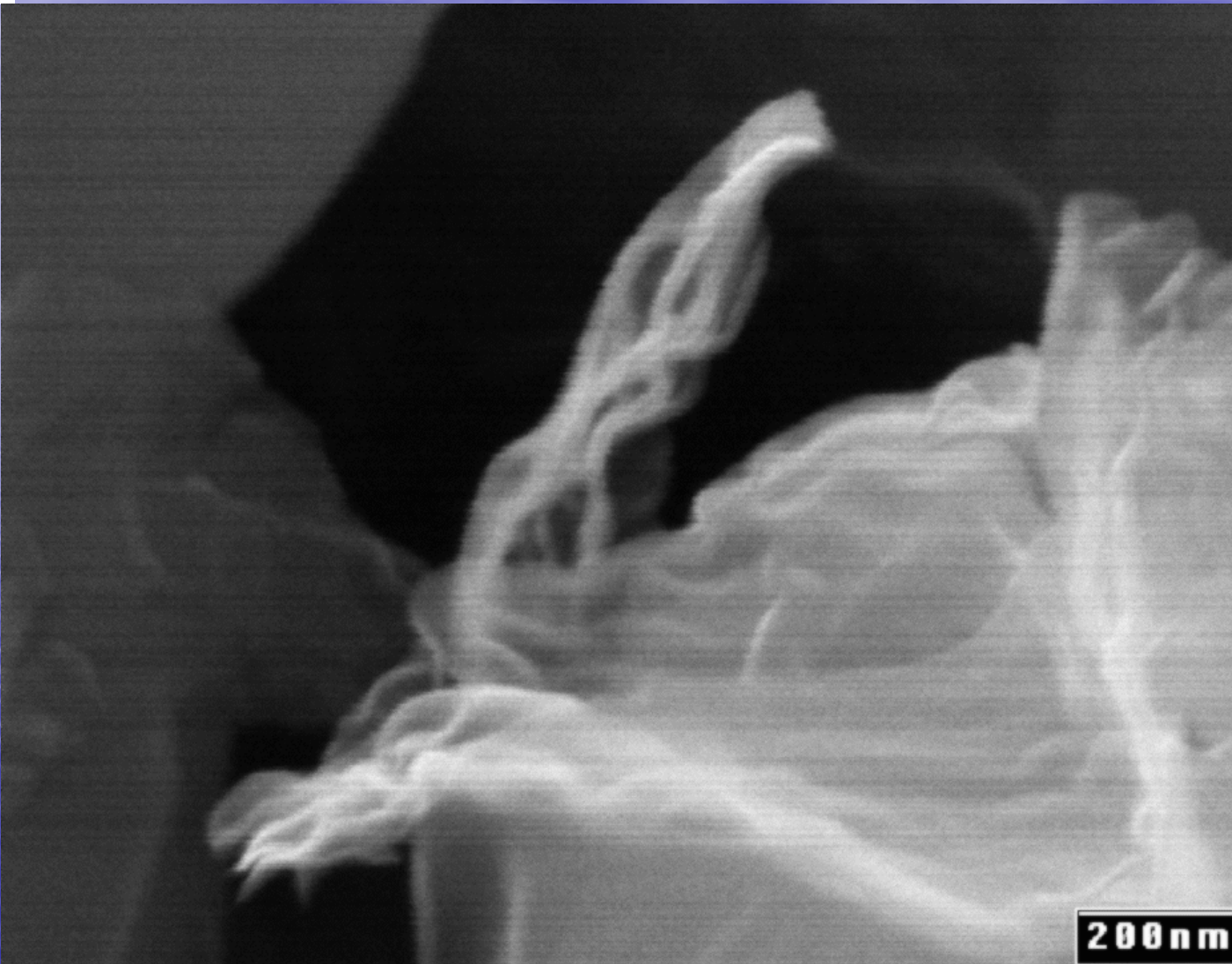
Nanostructures in Orgueil Filaments: Fimbriae



Filaments with Lophotrichous Tufts of Fimbriae



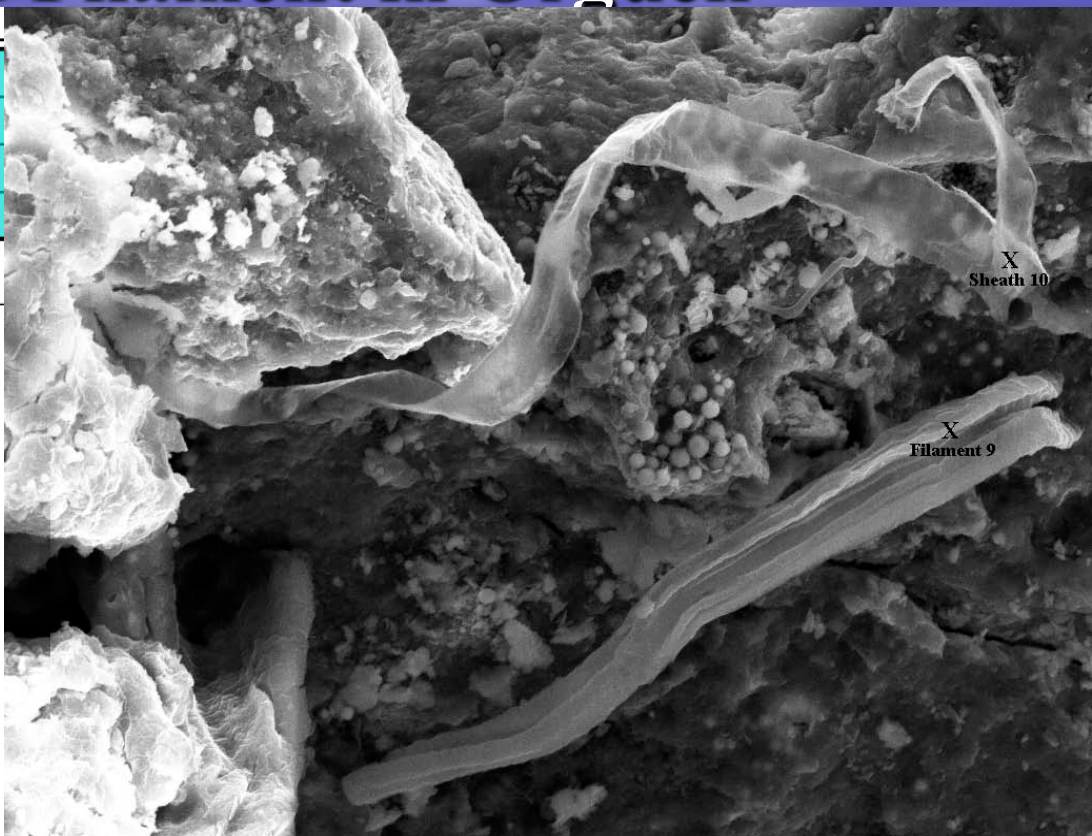
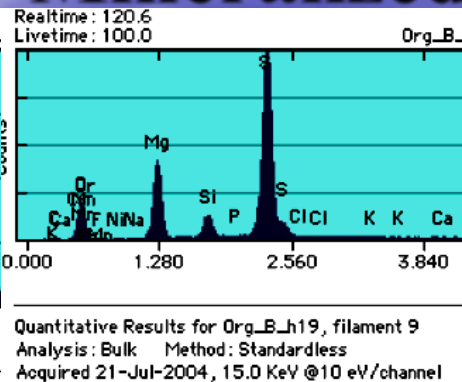
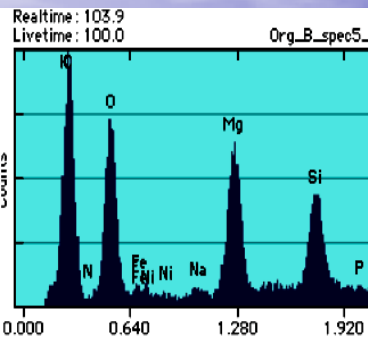
Nanostructures in Orgueil Filaments: Fimbriae



Lophotrichous Tuft of Fimbriae @ 80kX



Carbonized Flattened/Twisted Sheath 10 μm Away From Mineralized Filament in Orgueil

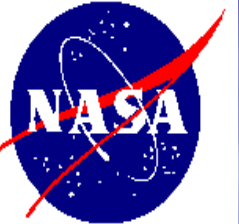


Atomic% - Flattened Sheath 10

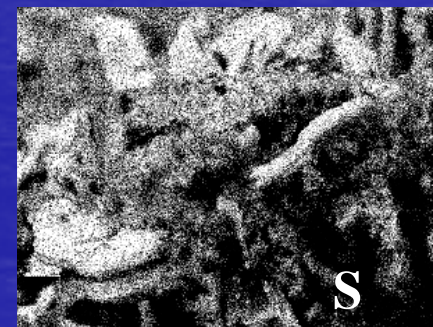
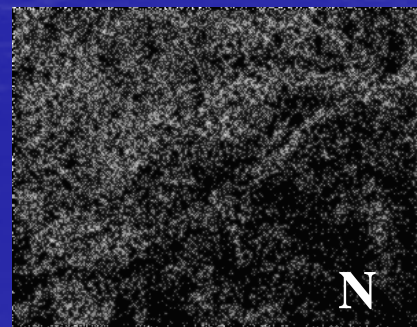
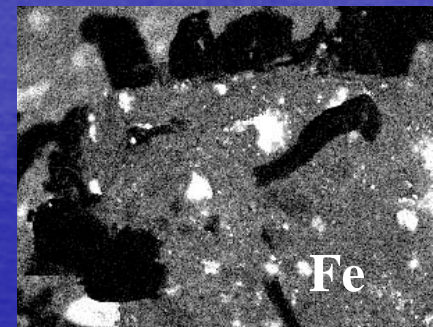
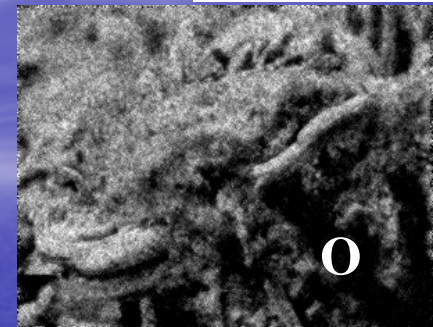
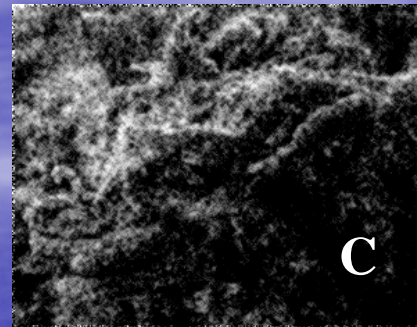
C 54.8%; S 17.2; O 13.4; Mg 6.1; Si 6.2; Fe 0.5; N 0% - O/C 0.24

Atomic% - Filament 9

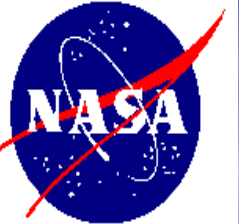
C 8.9%; S 33.8%; O 35.1; Mg 14.2; Si 4.0; Fe 3.1; N 0% - O/C 3.9



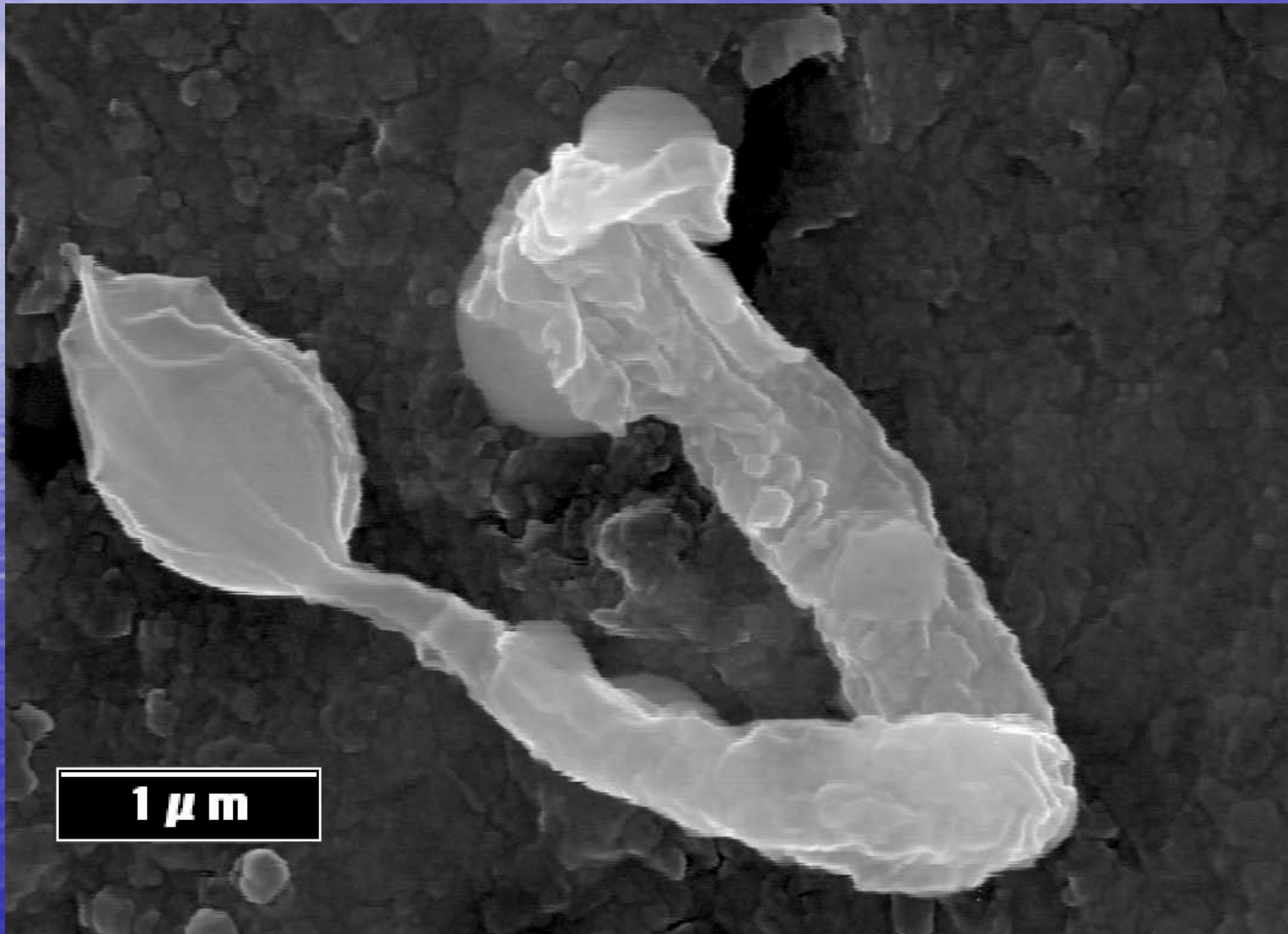
Indigenous Microfossils in Orgueil

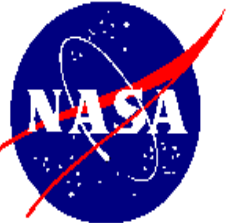


**Filaments and Sheaths Embedded in Orgueil Rock Matrix with
2D X-Ray Maps for Carbon, Oxygen, Silicon, Iron, Nitrogen & Sulfur**

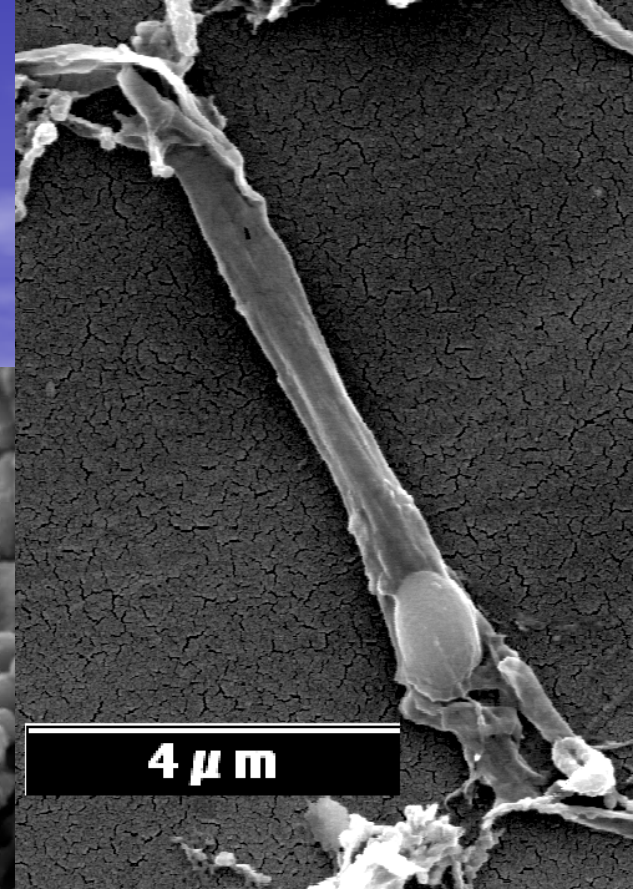
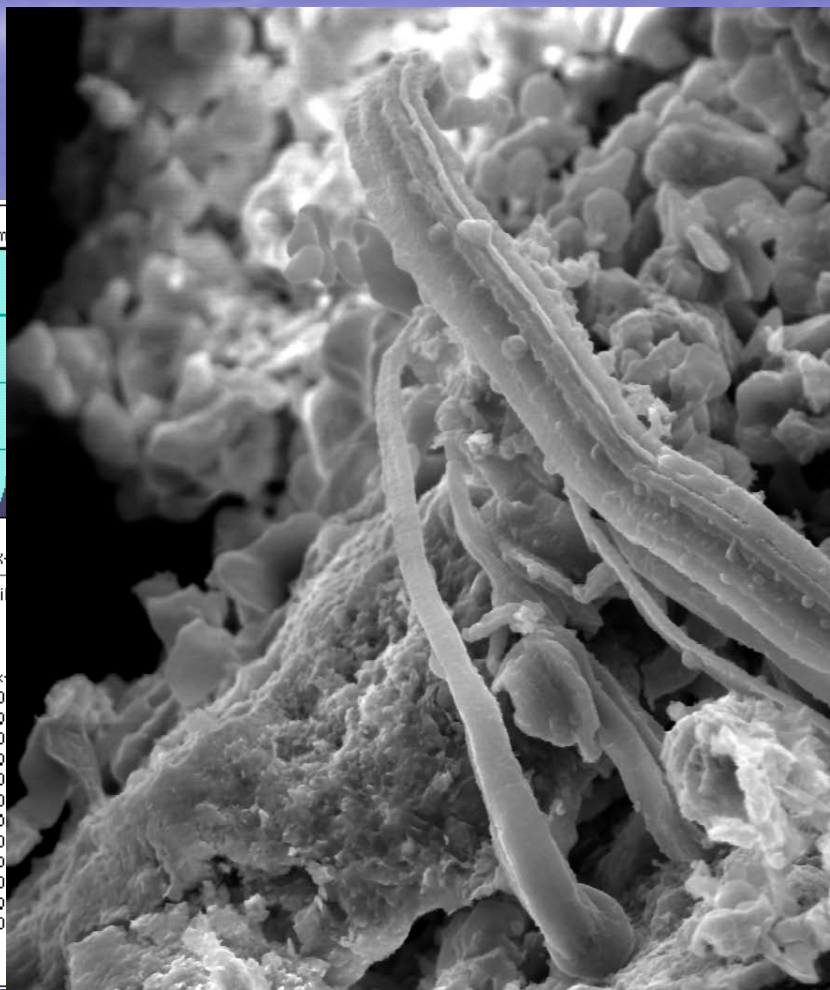
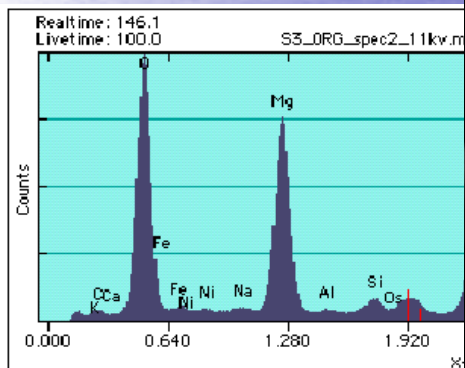


Morphotypes of Order *Nostocales* in Orgueil CI1 Meteorite : *Rivularia* ~ *Cylindrospermum* sp.

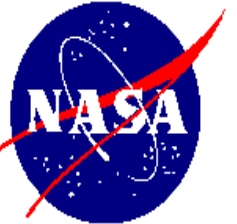




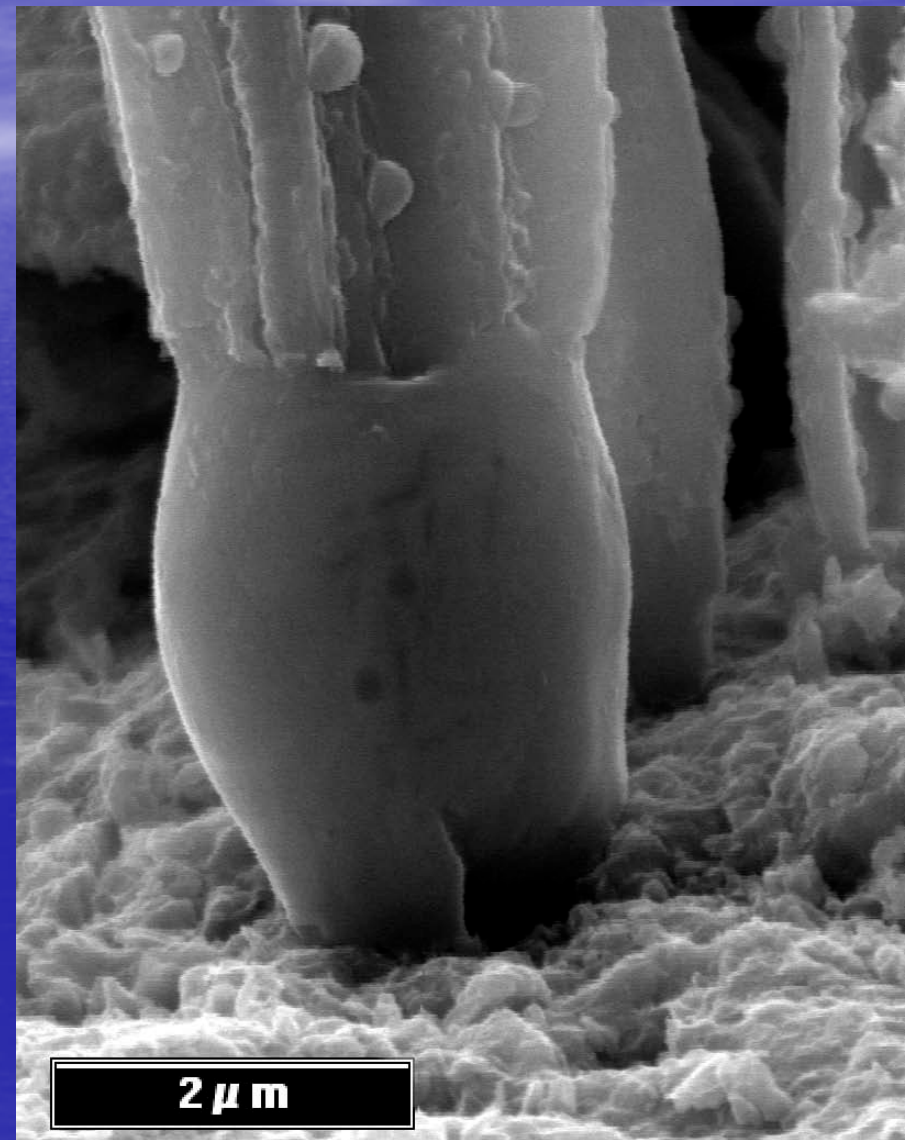
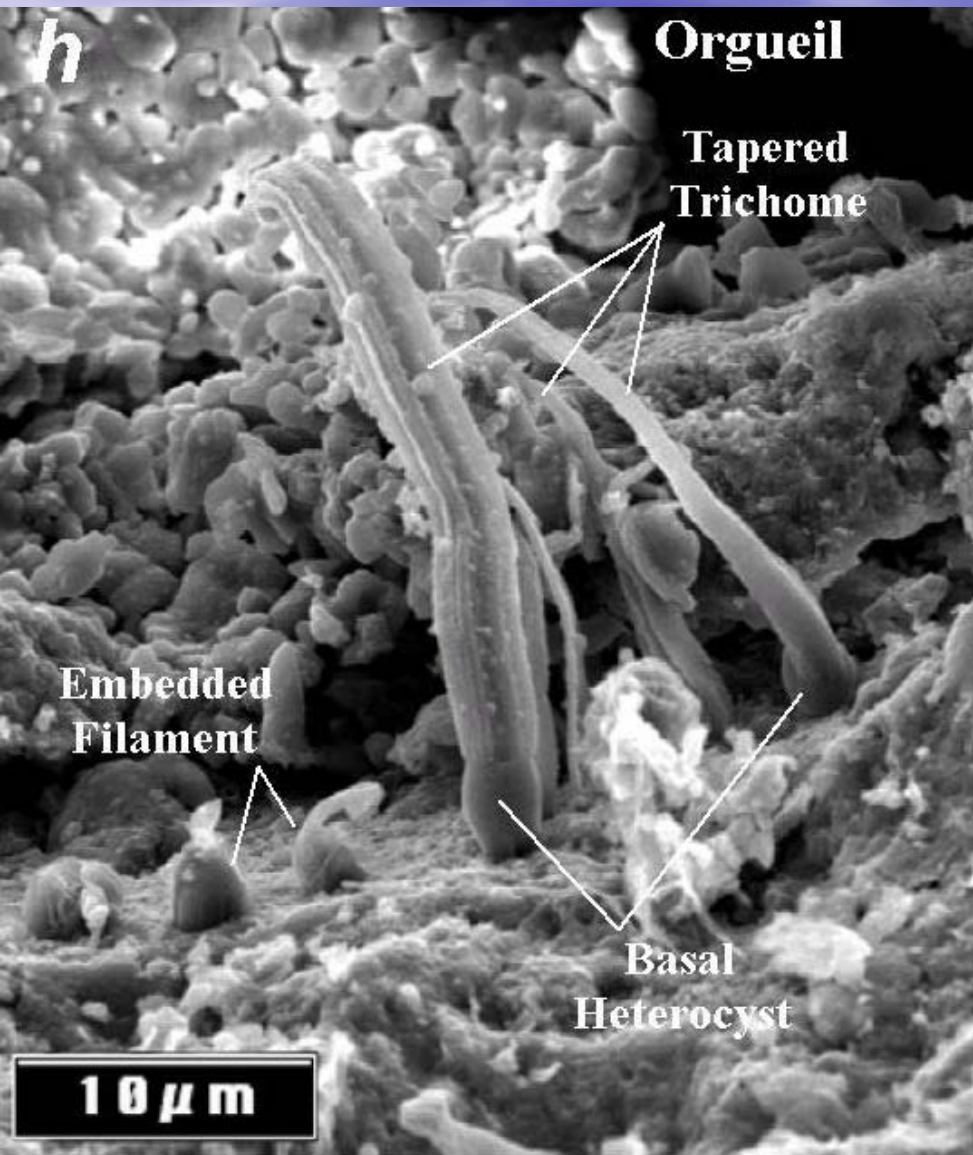
Morphotypes of Order *Nostocales* in Orgueil ~ *Calothrix* sp



Living *Calothrix* & Heterocystous Filament in Orgueil

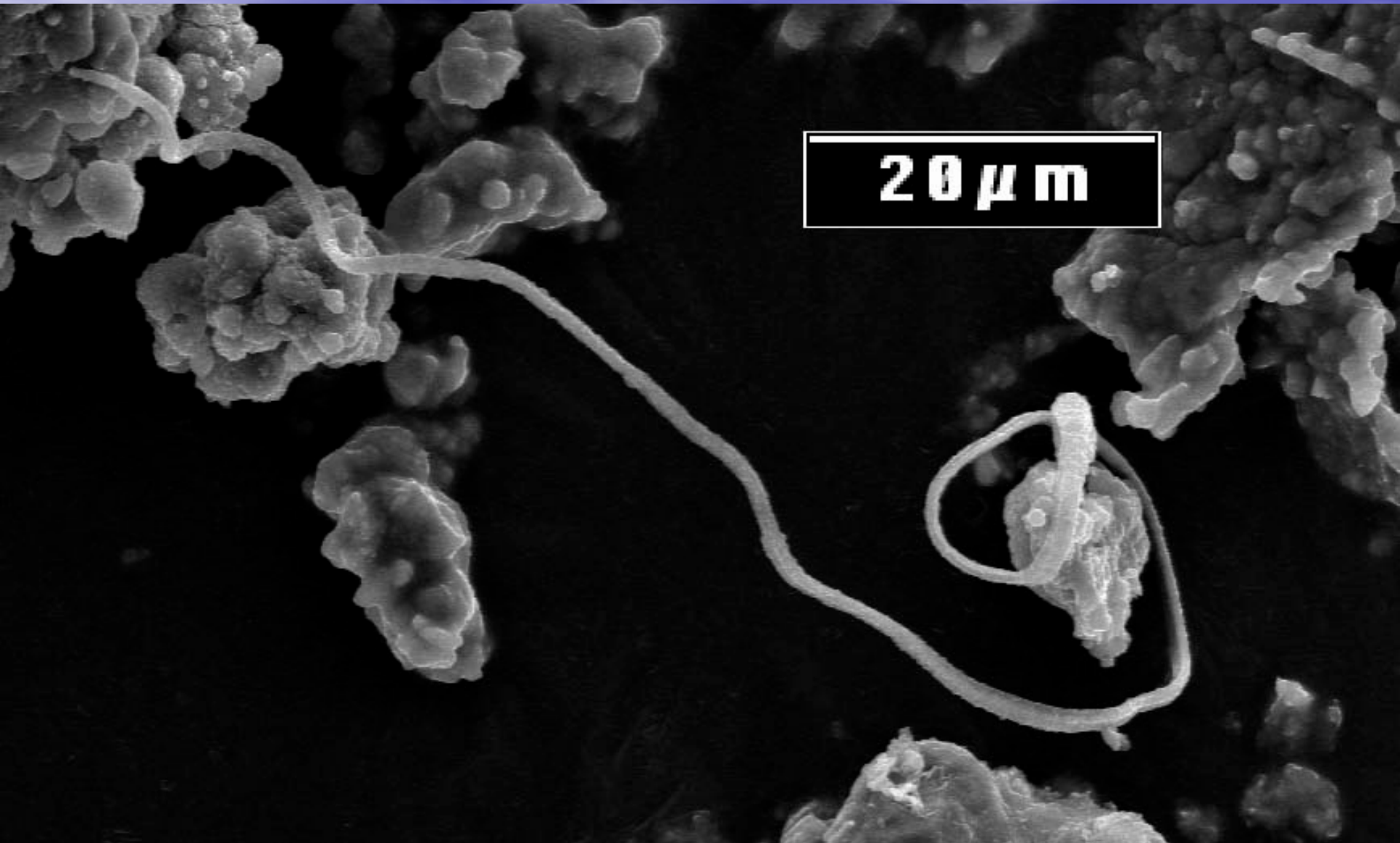


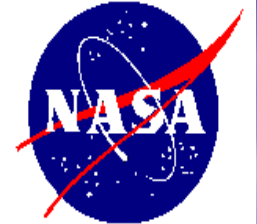
Morphotypes of Order *Nostocales* in Orgueil ~ *Calothrix* sp.



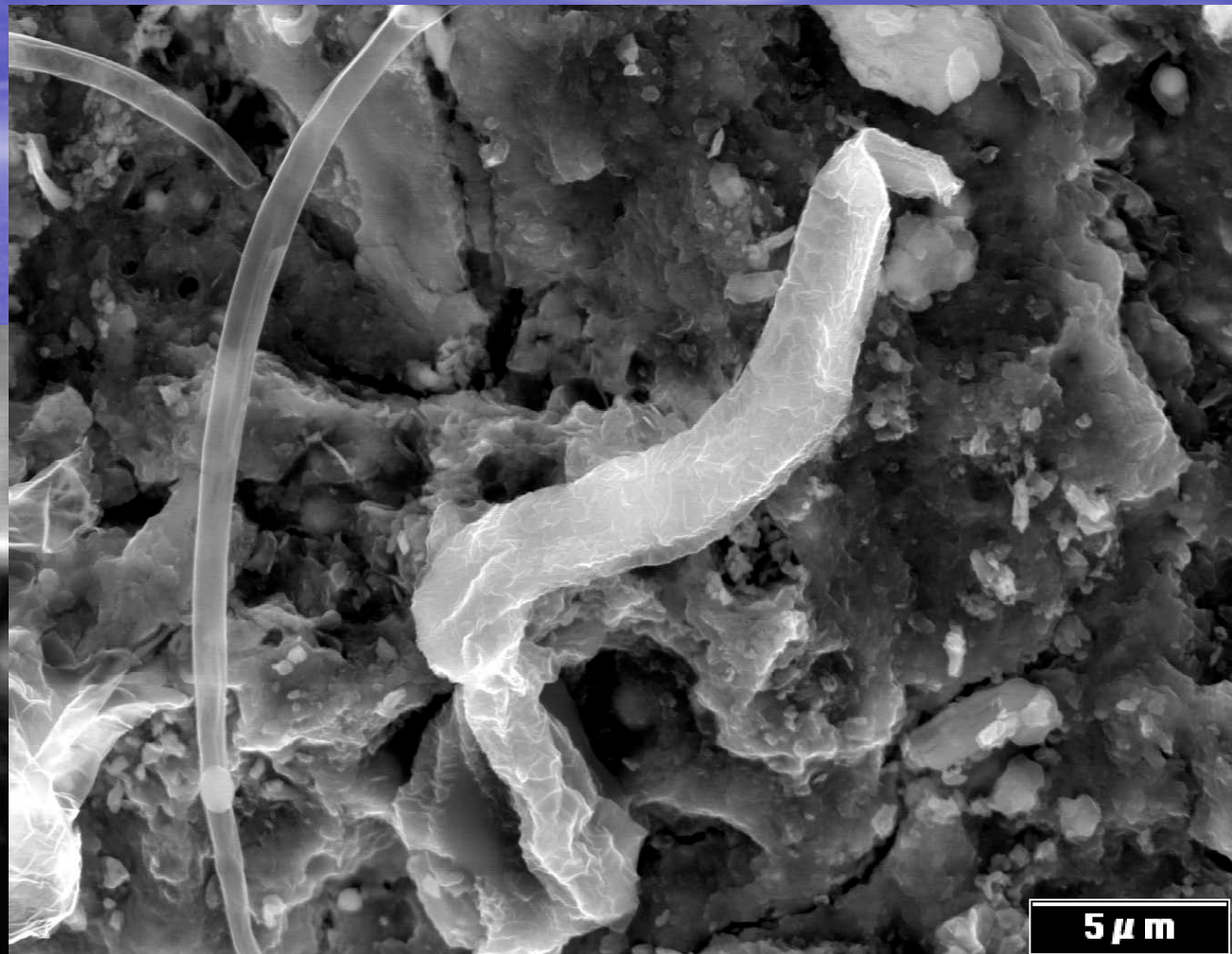


Rivularian Morphotypes in Orgueil *Cylindrospermum* sp.





Morphotypes of Order *Nostocales* in Orgueil with Intercalary Heterocyst ~ *Nostoc* sp.



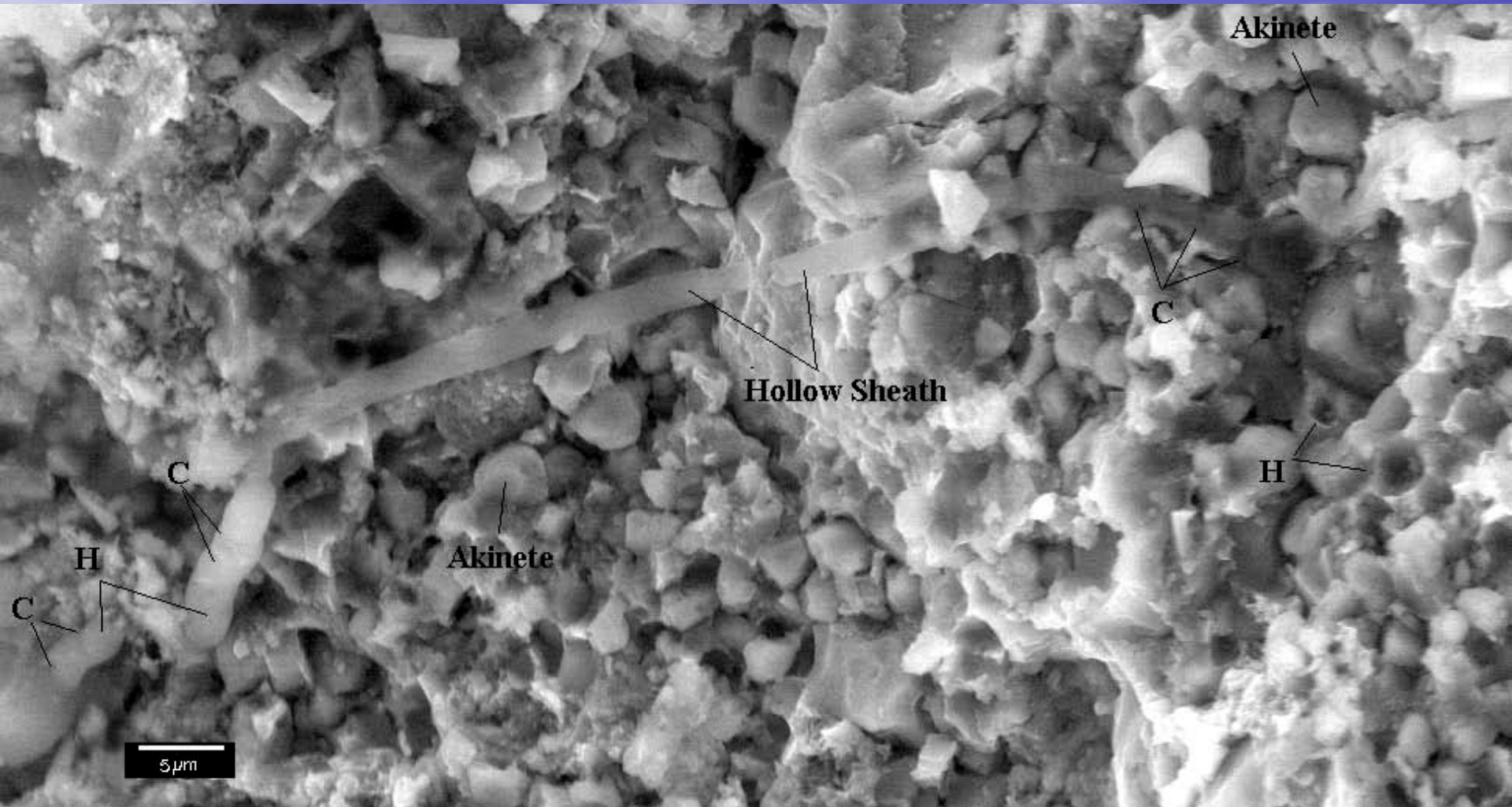
1 μm

5 μm

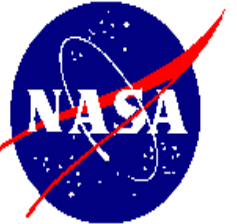
Hollow Sheath with Single Internal (0.8x1.4 micron) Cell



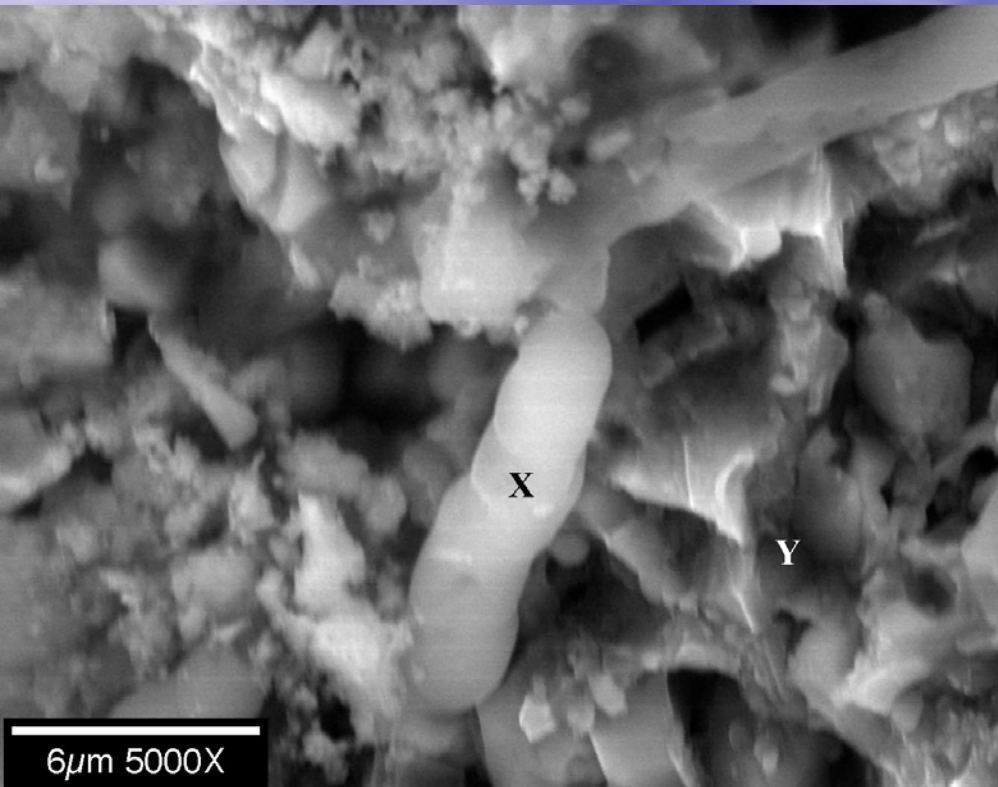
Morphotypes of Order *Nostocales* in Murchison with Hormogonium



Embedded Hollow Sheath, Emergent Trichomes & Coiling
Hormogonia (H), Cross-Wall Constrictions (C), and Akinetes

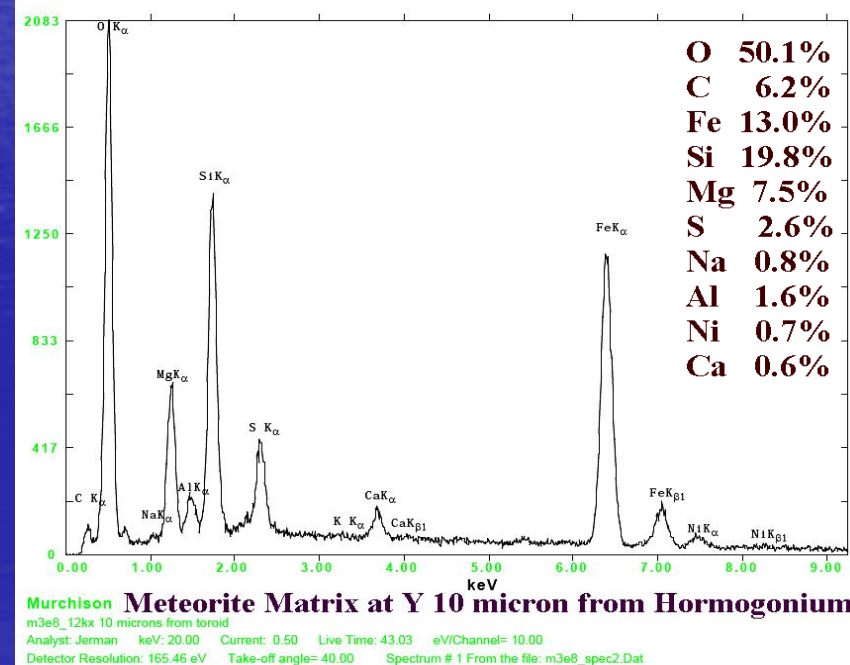
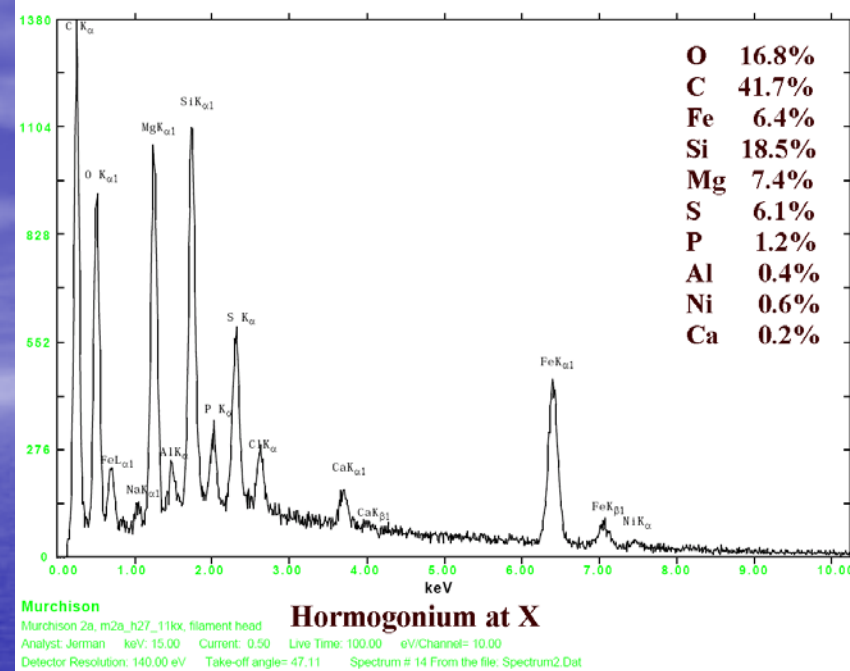


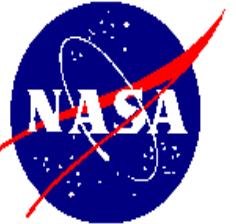
Carbon Enrichment & Nitrogen Loss



Constrictions in Emergent Trichome &
Flattened Sheath Indicate Spherical or
Cylindrical Cells ~ 2 μ Diameter

Hormogonium: C/N>83; O/C=0.3
Meteorite Matrix: C/N>12; O/C=8.0



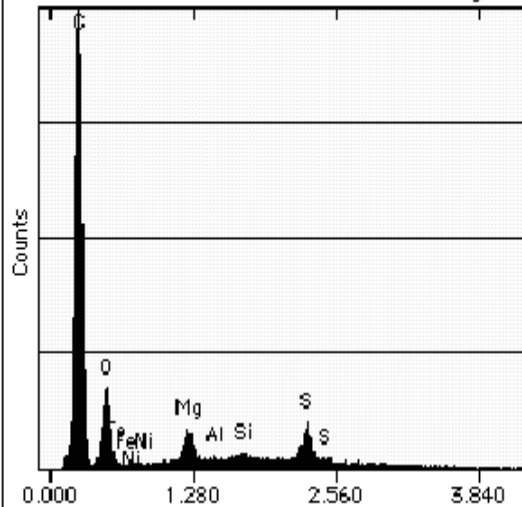


Morphotypes of Order *Stigonometales* in Orgueil



Realtime: 106.6
Livetime: 100.0

Org_E_spec2_5kV::Org_E_h20, sheath

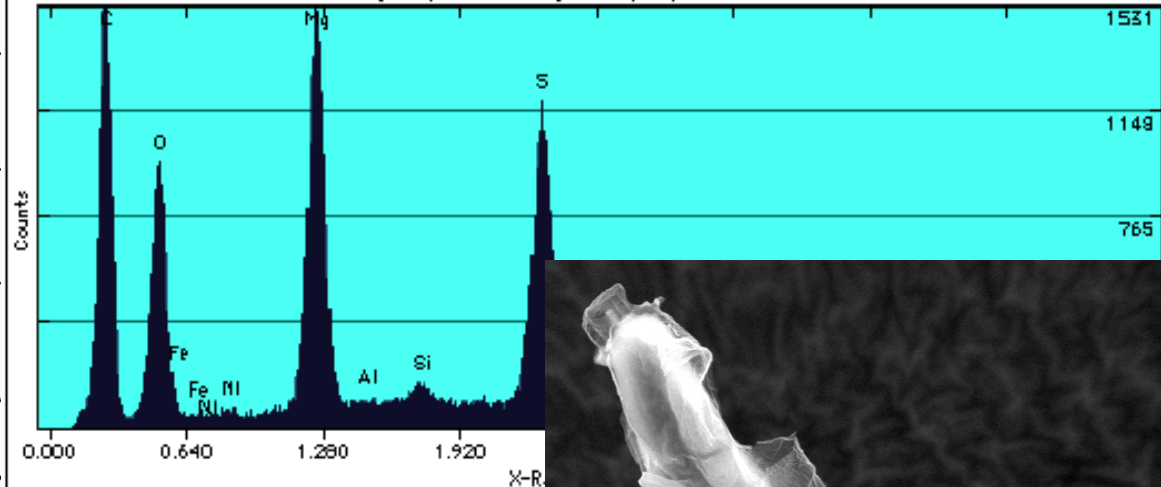


Quantitative Results for Org_E_h20, sheath
Analysis: Bulk Method: Standardless
Acquired 25-Aug-2004, 5.0 KeV @10 eV/channel

Element	Weight %	Std. Dev.	MDL	Atomic %
C	70.63	1.95	0.16	81.98
O	10.59	0.71	0.48	9.23
Mg	3.97	1.02	1.56	2.28
Al ?	0.00	0.00	2.10	0.00
Si ?	1.16	0.44	3.28	0.58
S	13.65	0.94	1.39	5.94
Fe ?	0.00	0.00	2.83	0.00
Ni ?	0.00	0.00	2.43	0.00
Total	100.00			

Realtime: 109.1
Livetime: 100.0

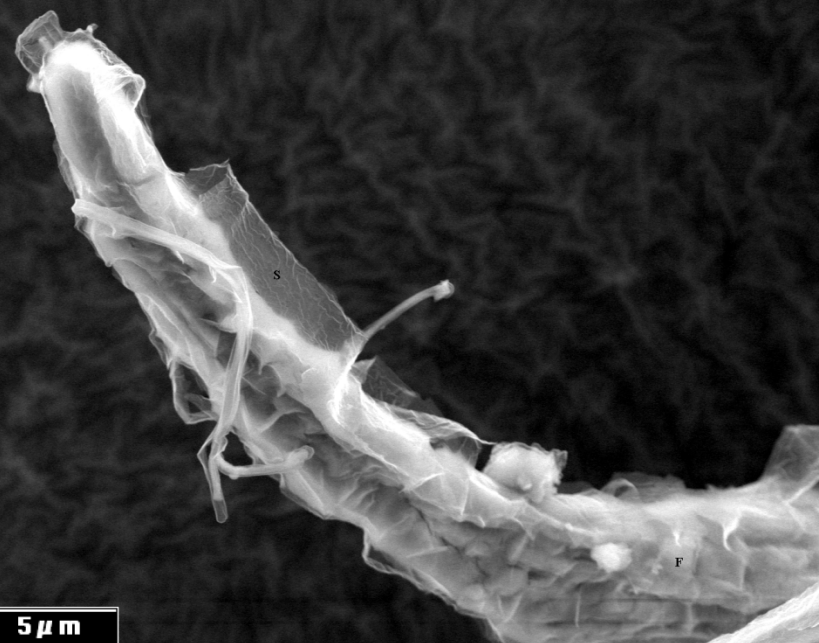
Org_E_spec2_5kV::Org_E_h20, large filament in sheath



Quantitative Results for Spectrum2
Analysis: Bulk Method: Standardless
Acquired 25-Aug-2004, 5.0 KeV @10 eV/channel

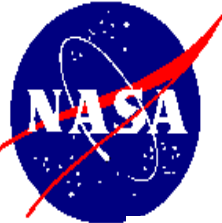
Element	Weight %	Std. Dev.	MDL	Atomic %	k-R
C	37.12	1.26	0.24	53.83	0.13
O	10.45	0.65	0.30	11.80	0.07
Mg	15.61	0.85	0.52	11.60	0.14
Al ?	0.00	0.00	1.60	0.00	0.00
Si ?	1.13	0.41	2.18	0.73	0.01
S	35.45	1.24	0.58	19.97	0.32
Fe ?	0.00	0.00	2.09	0.00	0.00
Ni ?	0.23	0.10	5.80	0.07	0.00
Total	100.00				

? These elements are statistically insignificant.



5 μm

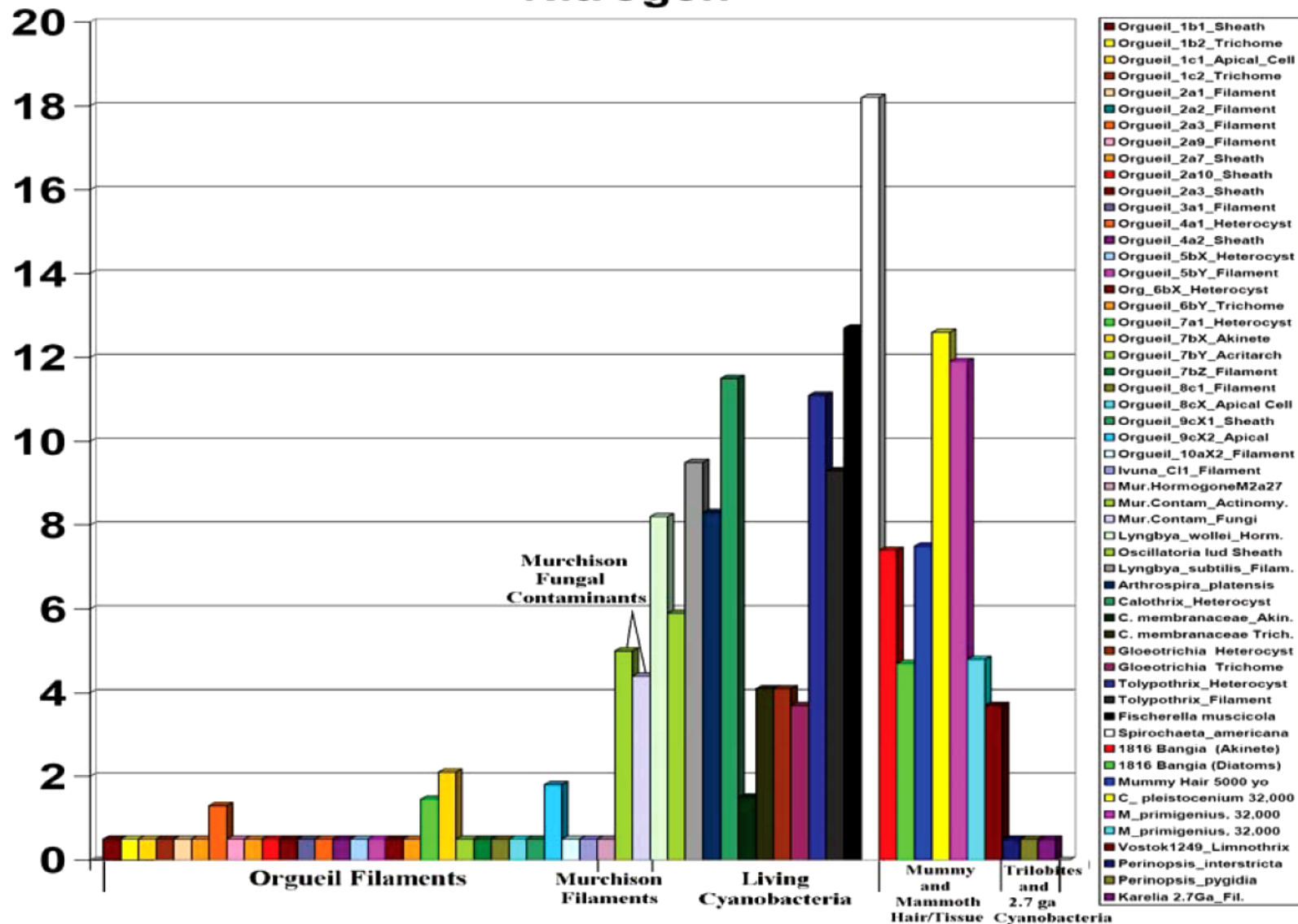
Epsomite infilled Cyanobacterial Filament (O/C=0.2) with Emergent Trichomes and Kerogenous Sheath (N< 0.3%; O/C=0.1)



Nitrogen in Meteorite Filaments, Modern Cyanobacteria & Ancient Biological Remains



Nitrogen





Biomarkers in Orgueil and Murchison Meteorites



Purines & Pyrimidines: Stoks & Schwartz, *Nature*, 282, 709, 1979

Chiral Amino Acids with Moderate to Strong L-Excess

Engel & Nagy, *Nature*, 296, 837, 1982; Engel Andrus & Macko in *Perspectives in Astrobiology*, Klewer NY, 2005.

Only 8 of 20 Protein Amino Acids Present: (Glu, Asp, Pro, Gly, Leu, Sar, Ala, Val)

Missing Amino Acids

(Phe, Tyr, Lys, His, Arg & Trp) – Present in All Life Forms

But Absent in Hadrosaur Fossils & Never Detected in Murchison or Orgueil Carbonaceous Meteorites

Porphyrins, Phytane, Pristane & NorPristane

Kissin, *Geochm. Cosm. Acta*, 67, 1723-1735, 2003

Pristand & Phytane - (2,6,10,14-tetramethylhexadacane) - C19 & C20 isoprenoid hydrocarbons derived from phytol chain of chlorophyll



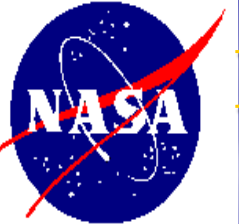
Filamentous Trichomic Prokaryotes in Carbonaceous Meteorites



Conclusions: Evidence of Indigenicity:

Orgueil Microfossils are found embedded in freshly fractured surfaces of meteorite matrix

- EDS Data Indicate forms are Carbonized or Mineralized Similar to Meteorite Matrix.
- Some forms are Devoid of Carbon and Others have Very High Carbon Content (~ Kerogen)
- Pollen Grains & Bio-Contaminants Not Detected
- Many Orgueil forms are Rare Species (Some of Entirely Unknown Biological Affinities)



Filamentous Trichomic Prokaryotes in Carbonaceous Meteorites



Are the Meteorite Filaments Biogenic?

The Orgueil & Murchison Meteorites Contains a Large Suite of recognizable Cyanobacterial Filaments with Trichomes encased within External Sheaths

All 5 Orders of Cyanobacteria were Found Embedded in Freshly Fractured Meteorite Surfaces

- Filaments, Trichomes & Sheaths of Cyanobacteria with Cross-Wall Constrictions, Septae and Fimbriae
- Evidence of Motility: Twisted & Spiral Hollow Sheaths & Emergent Trichomes and Hormogonia
- Evidence of Mats, Colonies & Macrocolonies
- Evidence of Special Nitrogen Fixation Cells-Heterocysts



Filamentous Trichomic Prokaryotes in Carbonaceous Meteorites

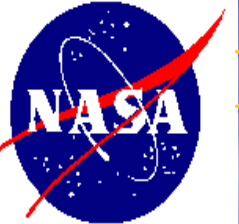


Evidence of Reproduction: Dividing cells, Diplococci, Chains of Cells, Akinetes, Cysts, Spores, Emergent Trichomes and Hormogonia

- Evidence of Ecologically Consistent Assemblages ~ Cryoconite Communities from Antarctica

Morphotypes of known species of *Microcoleus*, *Phormidium*, *Calothrix*, *Lyngbya* and *Spirolina* with associated *Hormogonia*, *Heterocysts* and *Fimbriae*

The Recognizable Cyanobacterial Filaments Found in the Orgueil and Murchison Meteorites are Undeniably Biological in Origin



Filamentous Trichomic Prokaryotes in Carbonaceous Meteorites



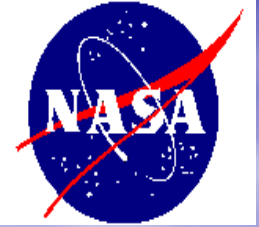
Are the Meteorite Filaments Modern Bio-Contaminants?

The Orgueil & Murchison Filaments Typically Contain Nitrogen at Levels Below EDS Detectability ($<0.5\%$)

Nitrogen is in All Amino Acids, Proteins, Enzymes, DNA and RNA Molecules in Living and Modern ($<100,000$ Yrs.) Organisms. Nitrogen Levels below 0.5% indicate Meteorite Filaments died long before Arrival on Earth.

Other Researchers have Detected only 8 of 20 Protein Amino Acids, 3 of 5 Nucleobases, no Ribose, Sugars or Chlorophyll in the Orgueil & Murchison Meteorites

Hence the Hypothesis of Bio-Contamination by Modern Cyanobacteria, Bacteria, Fungi, or Pollen is Rejected



Filamentous Trichomic Prokaryotes in Carbonaceous Meteorites



ACKNOWLEDGEMENTS

- *Electron Microscopy Support* - Gregory Jerman & James Coston
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- *Meteoritics*:

Claude Perron, MHNP

Academician Eric Galimov, Vernadsky Institute, RAS

- *Microbiology and Cyanobacteria Discussions*:

Academician Georgi Zavarzin; Ludmilla Gerassimenko-Institute of
Microbiology, RAS

Richard Castenholz-Univ. Washington

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